Improvement of Wireless Network Infrastructure with new architect elements based on new Relay Station (RS), focusing on evaluation of secure prototype.

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by

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1. Abstract

This thesis examines how to improve the effectiveness of wireless network infrastructure, using Wimax technology combined with Relay Station (RS). This project aims to bring a revolution in terms of network capacity and coverage while reducing expenditures. Relay Stations can provide the necessary capacity and coverage to support new wireless applications as well as broadband and Quality of Service. Spectrum reuse, low cost and easy installation of Relay Station are only two of the most important advantages of this project. WiMAX could be compatible with Relay Stations and effective backhauling infrastructure and could offer the expected results of the dissertation. This dissertation will be based on WiMAX the most advanced, available and standardized broadband wireless technology. This project is big enough for one academic person, so the above project has been shared in the following partners:

Technological Educational Institution (T.E.I.) of Athens (GR),
Ubiqam Ltd. (IL),
Hellenic Telecommunications Organization S.A. (GR),
Centro de Tecnología de las Comunicaciones, S.A. (AT4 wireless) (ES),
Codium Networks S.L (ES),
DesignArt Networks Ltd. (IL).
I participate in Hellenic Telecommunication Organization S.A. works, more specific in Work Package 8, for laboratory Test Architecture and Field Tests.

2. List of Abbreviations

Acronym	Defined as
3GPP	Third Generation Partnership Project
ACLR	Adjacent Channel Leakage Ratio
ARM	Advance RISC Machines
ASN	Access Service Network
ASN	Access Service Network
ASN-GW	ASN Gateway
b	the number of TCP packets acknowledged by one ACK
B	TCP end-to-end throughput
BE	Best-Effort Service
BH-SF	Backhaul Service Flow
BTS, BS	Base Transceiver Station
CC	Convolution code
CID	Connection ID
COTS	Commercial Off-The Shelf
CSN	Connectivity Service Network
CTC	Convolution Turbo Code
Dd	typical down-link wireless delay
DL	Downlink
DL-MAP	Downlink Map
DP	Data Path
DPF	Data Path Function
Du	typical up-link wireless delay
FA	Foreign Agent
FCH	Frame Control Header
FRS	fixed relay station
HA	Home Agent
k	average number of ARQ (re)transmissions per TCP packet
LOS	Line of Sight
m	maximal ARQ retransmissions
MAC	Medium Access Control which is consists of MAC header and the MAC SDU
MIP	Mobile IP
MMR	Mobile Multihop Relay
MRBS	Multi-hop Relay Base Station
MR-BS	multihop relay base station

Acronym	Defined as
ATM	Asynchronous Transfer Mode
MRS	Mobile RS
MS/SS	Mobile Station / Subscriber Station
NLOS	Near Line of Sight
NMS	Network Management System
NRS	nomadic relay station
nrtPS	Non-Real-Time Polling Service
NTR	Non Transparent Relay
NWG	Networking Work Group
O LOS	Obstructed Line of Sight
OFDM	Orthogonal Frequency Division Multiplexer
OFDMA	Orthogonal Frequency Division Multiple Access
p	wire-link loss rate
pARQ	residual down-link packet error rate after ARQ
PMIP	Proxy Mobile IP
pPHY	down-link physical layer packet error rate
PSK	Phase Shift Keying - Binary PSK (BPSK), Quadrature PSK (QPSK)
QAM	Quadrature Amplitude Modulation
qARQ	residual up-link packet error rate after ARQ
QoS	Quality of Service
qPHY	up-link physical layer packet error rate
QPSK	Quadrature phase shift keying
R	TCP average round-trip time
R-FCH	relay zone frame control header
RISC	Reduced Instruction Set Computer
R-MAP	relay zone MAP
RRA	Radio Resource Agent
RRC	Radio Resource Controller
R-RTG	relay receive/transmit transition gap
RS	relay station
RS	Relay Station
RSIN	Relay Support Infrastructure
RSRTG	RS Receive/transmit Transition Gap
RSTTG	RS Transmit/receive Transition Gap
rtPS	Real-Time Polling Service
R-TTG	relay transmit/receive transition gap
R-Zone	relay zone

Acronym	Defined as
SA	security association
SDU	Service Data Unit
SF	Service Flow
SFN	Single Frequency Network
SFS	Schedule Flow Sub channel
SM	Spatial Multiplexing
SNR	Signal to Noise Ratio
STBC	Space Time Block coding
STR	Simultaneous Transmit and Receive
T-CID	Tunnel CID
TDD	Time Division Duplex
TDMA	Time Division Multiplexer Access
TEK	Traffic Encryption Key
TTR	Time-division Transmit and Receive
UGS	Unsolicited Grant Service
UL	Uplink

3. List of Tables

4. Chapter I - Introduction

This project examines backhaul Relay Station implementations for WiMAX and supports the relevant standardisation process with interoperability, in addition takes lab and field information on possible implementations of the WiMAX relay. This project focuses on one of the most important concepts in wireless network infrastructure. It is believed that it will revolutionize the level of wireless broadband services in areas of network capacity and coverage simultaneously bringing profits with low cost effective.

The existing wireless infrastructure uses WiMAX technology. It follows the first 802.16-2004 standards of IEEE. Modulation is OFDM which does not group channels like OFDMA. WiMAX has replaced the previous technology: Decktlink & SAR. Base Stations are installed in the same piles of last technology therefore the hole problems are remains. Through put reached 7 Mbps under best conditions, typical 2 Mbps, at 3,5 Ghz. This limit restricts a lot of new applications.

This Relay Stations base on Wireless Network and will create a flexible infrastructure with low-cost budget, easily installation, providing the necessary capacity and coverage to support new wireless applications with similar QoS (Quality of Service) to currently available only through wired broadband service (e.g. DSL). At the same time the Relay Station could provide access and an efficient backhauling mechanism which will maximize utilization of the infrastructure capacity and spectrum reuse, without need additional Capital Expenses (CAPEX) or Operational Costs (OPEX) associated with dedicated backhaul. It is looking to develop state-of-the-art technology, products and network that will have effect on the network of the future in the coming years, it bases on WiMAX, the most advanced, yet available and standardized broadband wireless technology.

The main concept of this project is to *examine the realization of the new wireless network architecture.* It is obvious that the next generation of wireless technology (whether this is WiMAX, LTE or any other 4G implementation) to be able to deliver ubiquitous broadband content, so the network should provide excellent coverage and throughput per subscriber. The licences which have been given concern frequencies in 2 and 3 GHz, which are targeted for future wireless technologies, network architecture must reduce significantly the cell size or the distance between the network and subscribers' antennas. The shrinking of the cell size also has provided crucial solution to the problem of the growing antenna panic mainly in urban areas with visible antenna infrastructure.

While base transceiver station (BTS) or cell site is shrinking consequently it is reducing the cost of base-station equipment which results in significant CAPEX and OPEX to the network operator. This concept which based on wireless Multi-hop Relay Station (RS) provides easily installation to enable mass deployment in indoor and outdoor environments to create relatively small areas with excellent coverage and high capacity availability. In addition, it does not require any dedicated backhaul equipment as it receives its capacity from centralized base-stations via the same resources which are used for the access service.

The reason for WiMAX is that this technology is currently the most advanced wireless technology available for deployment and many of its subjects could be implemented in any 4G wireless technologies. Relay stations standardization has already commenced by the IEEE under the 'Multi-hop Relay Task Group' also known as 802.16j. The project supports these standard processes, through research and development of relay technology in order to assist the standard body with interoperability in the lab and field on possible implementations of the WiMAX relay.

The evaluation of the Wireless Network using Relay Stations should be scrutinized of lab and field performance tests. The stability and the consistent functionality of the system are the main factors which will be tested under certain circumstances with the help of specialized network equipment. Test procedure will play a key role on the development and qualification of prototype multi hop relay units. User requirements, user scenarios and business case analysis will take into consideration for the test procedure.

Each part of prototype will be tested and if it is possible it will be calibrated in order to have the minimum number of errors in the final product.

In two major parts, the testing procedure will be distinguished. The first task has to do with in-lab testing of the prototype equipment. Initially the prototype will be qualified under a certain testing methodology, covering thus all possible test-cases.

During the testing phase, the above mentioned methodology will be constantly adapted to the feedback, which will be gained from new possible scenarios and evolution of the product. At the final stages of in-lab testing on system's functionality and performance, a result analysis report will composed.

This detailed analysis will provide the necessary feedback to the participants involved in the development process, so that improvements to the prototype are made before the next testing part, which is the field testing of the prototype system starts.

Initially, the second task will run in parallel with in-lab testing so that improvements that are made during the first stages of field tests are also tested in laboratory environment. The Multi-hop Relay Base Station will be tested under certain procedures, at the interoperability level, in conjunction with various 802.16e products and other WiMAX network elements that a telecom operator could use. In addition to the interoperability tests, the system will be tested under increased load conditions, so that its stability is proved.

5. Chapter II - Literature Review

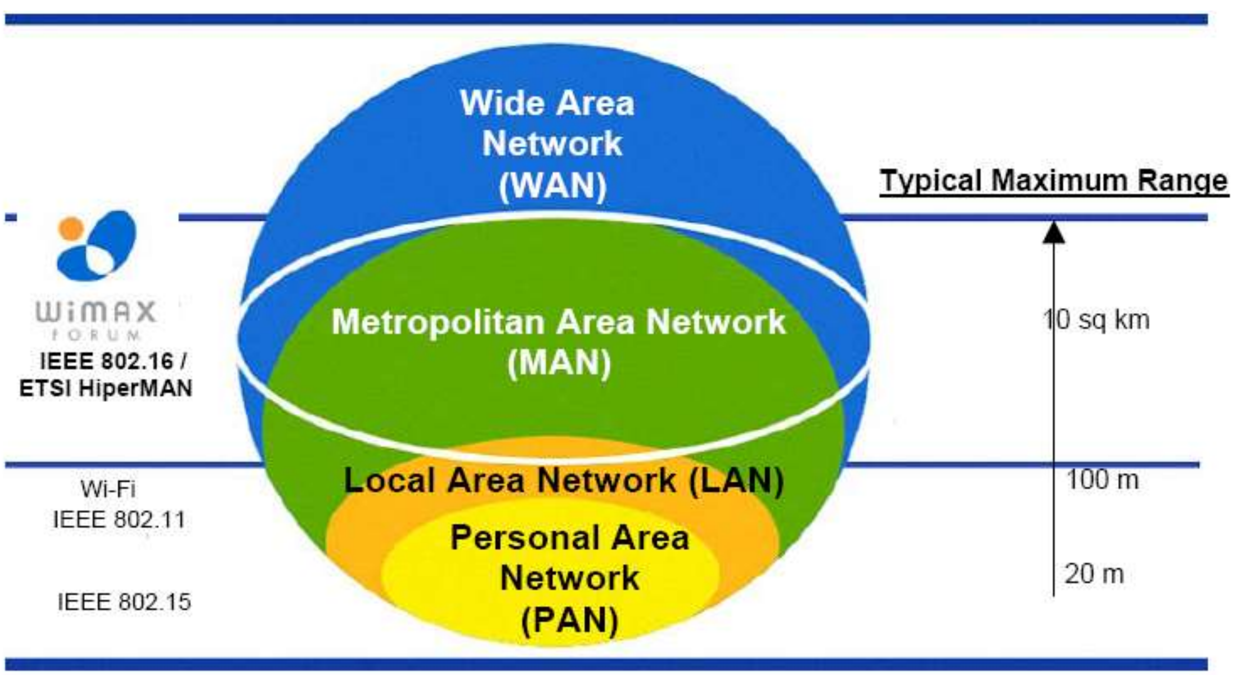
There are few references and highlight my individual contribution to knowledge. The aim is to present sufficient depth of analysis within literature review.

This Section depicts the state-of-the-art of the main subjects addressed in our project like Standard IEEE 802.16 Broadband Wireless Access (WiMAX technology). All these affairs include wireless network topology that has been used for the improvement of the link communication between the operator and the customer premises.

1. IEEE 802.16 and 802.16j Broadband Wireless Access

WiMAX technology is based on two standards, the **IEEE 802.16** and the ETSI HiperMAN. Both of standards serve as the basis for WiMAX Forum air interface specifications at the PHY and MAC layers. IEEE 802.16e based on Orthogonal Frequency Division Multiple Access (OFDMA) this standard version supports fixed and nomadic access, but it also includes additional capabilities to serve mobile access.

IEEE & ETSI Standards for Wireless Network:



This project transfers us further than 802.16 project to 802.16j (Mobile hop Relay). It unfolds a scenario using RS for fixed, mobile and hybrid network. So, it achieves to improve the system performance, coverage and increase throughput.

RSs can be used on existing infrastructure with new type of services-through these- and the performance goals. The combination of **RS**s and **MMR**-**BS**s (Mobile Multihop Relay – Base Station) can enhance the extend coverage to areas where it is not sufficient or there is low throughput. The provider can plan the desirable locations of RS antennas obtaining generally LOS (Line of Sight) channels between the MMR-BS and RSs, but this will not always be practical, so Non LOS channel conditions on links between MMR-BS and RSs can be expected due to unforeseen obstacles.

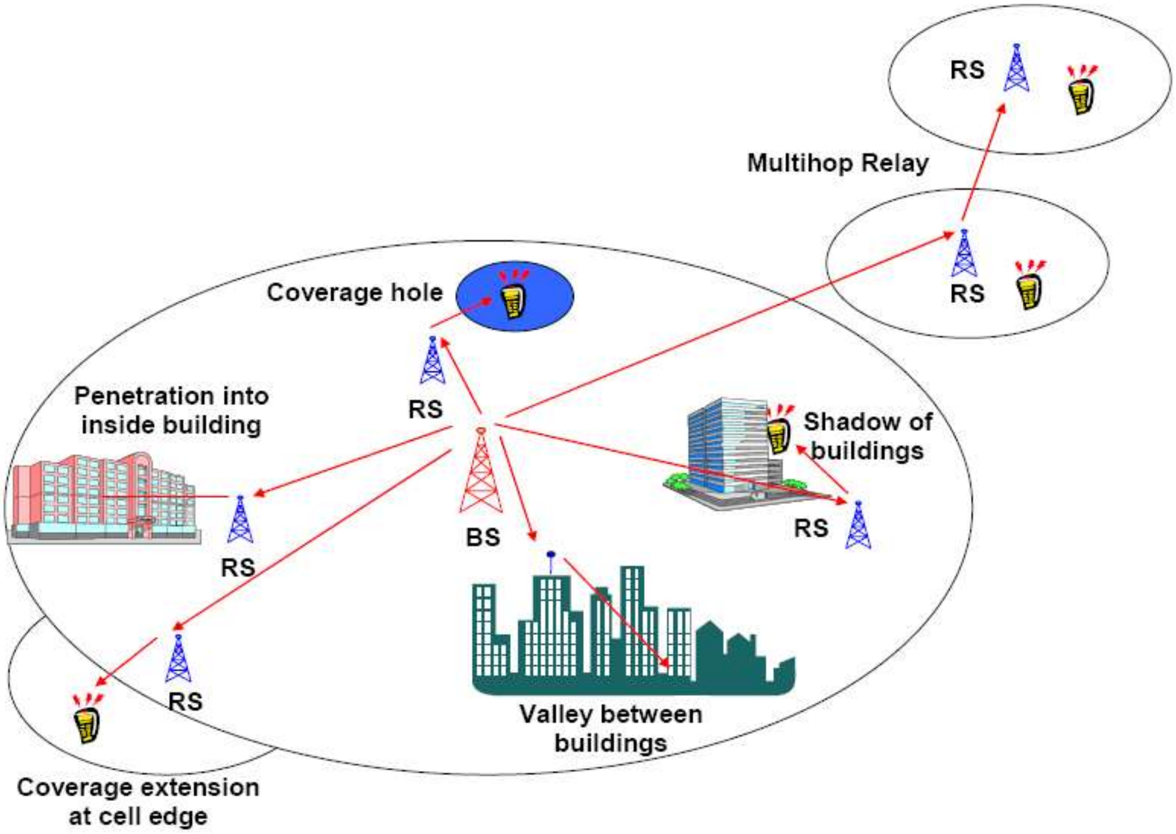
An advantage of RS is easy mounting. It can be mounted without specific requirements, on towers, poles, tops or sides of buildings, lamp posts, or in other locations.

Consequently, the types of links which our system can cover are: LOS areas, Optical LOS (out of Fresnel zone) areas and NLOS this case usually is not preferable because we need more antennas mounted outside or inside of the building.

So, infrastructure can be deployed easily and make new routes in order to balance the traffic load. Communication paths in topologies could include a range from 2 hops to multiple hops (in practice up to 2-3 wireless hops). The best route is selected which depends on balance of the traffic load and priority of service.

A military environment makes another scenarios, there RS site may be pre-planned and carefully designed to provide enhanced connectivity and capacity to MS/SS (Mobile Station / Subscriber Station) users.

The figure below illustrates the deployment of RSs, to provide extended coverage at the edge of the cell, to provide coverage in holes that exist due to shadowing and in valleys between buildings, and to provide access for clusters of users outside the coverage area of the BS.



It is adapted from 4.1 Example Use Cases from Fixed Infrastructure Usage Model, IEEE 802.16j-06/015, 2006.

Mobile RS can be used on vehicle such as a bus or a train or ferries and offers a fixed access link to MS/SS (Mobile Station / Subscriber Station) devices riding on the platform. Mobile RS, in those cases, operates in the network all of the duration of vehicle is in service. In this topology communication path may include 2 or more hops.

An example of a multi hop topology is the case where the train travels through a tunnel and the mobile RS onboard of the train connects to MMR-BS directly or via RS which are deployed along the tunnel.

One RS may need to coordinate with other RSs to provide better service to the MS/SS. Mobile nodes (MS / SS) comprise of similar platforms (i.e. vehicles) used within commercial applications. In this case a station may need to operate as either a BS or RS and additional, in difficult condition like an RS losing connectivity to its upstream RS or MMR-BS, then it may be able to switch roles in response to conditions in the field.

In accordance with 802.16j deployments comprise of two available ways which they can be used for increasing per-user throughput, system capacity, and reliability. First, RSs can increase the SINR or SNR ratio to users at the edge of the cell, where SNR = P of signal / (P of noise + P of interference) and P is average value of power. In that case there is not only one low SINR link but higher SINR links, obtaining higher modulation by supporting of code rates.

Capacity can increase when spectral efficiency are used when transmit data over multiple hops. Consequently, a higher throughput is available to MS/SSs or to support more users within the coverage area of the RS or by MS. Higher SINR means higher link reliability.

Second, RSs and MMR-BSs can improve the capacity within dense areas then the cells becoming smaller, so the infrastructure is being enhanced. This permit increased routing diversity through RS nodes avoiding congestion between RS links.

MMR-BS and RSs are useful for several different situations which they can expand the coverage area of the network, giving solutions. For examples three cases are following. First, a hole can be covered if an RS is added. When throughput becoming lower in a shadow of a building or due to other obstruction then RSs can be deployed providing enhanced throughput to MSs. Third, when there is dense urban environment deployment of RS can give a solution.

Supported Link Types

The following types of links as the following illustrated can be use in our topologies:

- MMR-BS to MS/SS – The MMR-BS can associate with multiple MSs
- RS to MS/SS – RSs can associate with multiple MS/SSs
- MMR-BS to RS – The MMR-BS can associate with multiple RSs.
- RS to RS– RSs can associate with multiple RSs.

Route Types

Symmetric or asymmetric routes (Uplink / Downlink) can be implied between the MMR-BS and MSs through zero or more RSs.

Table 1 Usage models

Model	Use Case Examples b	Performance Objectives	Topologies
Fixed Infrastructure	(1) Cell Edge, (2) Coverage Holes (shadowing from trees, buildings, valleys), and; (3) Outside cell area	Coverage, capacity, range	Fixed
In Building Coverage	(1) Inside building (2) Inside tunnels (3) Under ground	Coverage, capacity	Fixed, Nomadic
Temporary Coverage	(1) Emergency/disaster recovery (2) Special events	Coverage, capacity, range	Nomadic
Coverage on Mobile Vehicle	(1) Inside buses and taxis (2) Inside Ferries (3) Inside Trains	Coverage, capacity, range	Mobile

2. All-IP Network Architecture for Mobile WiMAX

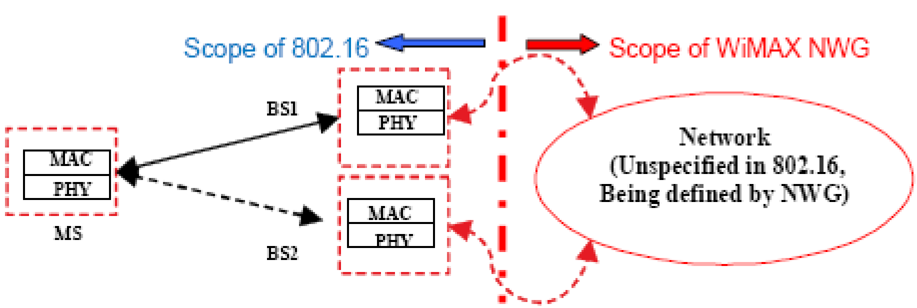
The mobile broadband wireless is under development and it will bring significant news of capabilities, delivering multimedia IP services anytime, anywhere.

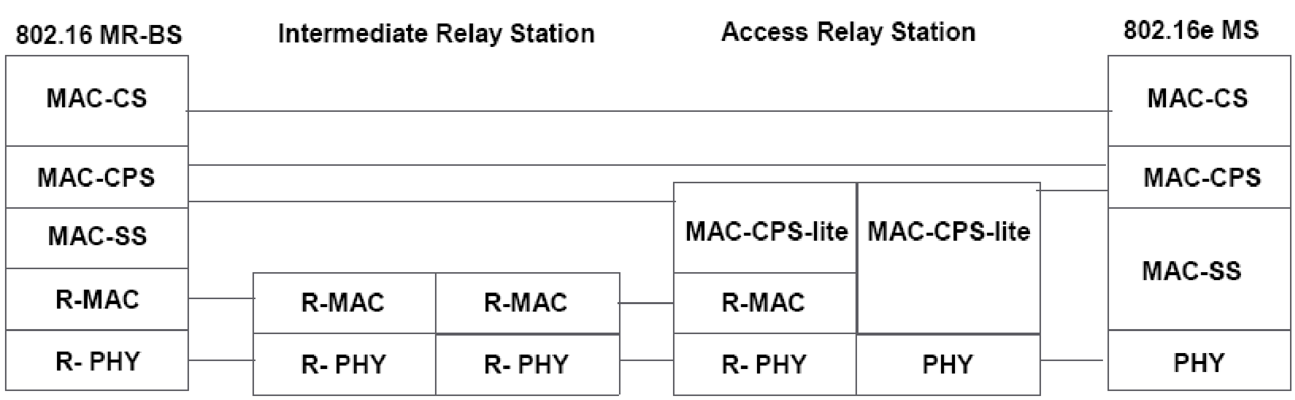
Mobile WiMAX network architecture uses a next-generation of modulation the OFDMA-based broadband wireless technology. The all-IP mobile network specification is being defined by the Network Working Group (NWG) in the WiMAX Forum.

Mobile WiMAX is able to deliver a range of IP services. Simultaneously, there is another significant goal that it penetrates the market faster than similar commodities due to lower capital and operational expenditures. Another goal which is inherent in new modulation is low latency and non-real-time applications can be operated. OFDMA leads to high services like Quality of Service management, security, radio resource function, hand over and low power idle mode which are in terms of key functions.

In order to achieve convergence between fixed and mobile WiMAX operations or between client device and a Base Station (BS), two common levels are used the physical layer (PHY) and Medium Access Control (MAC) radio. Sub-layer Convergence Sub-layer (CS) allows multiplexing various types of network traffic into the MAC layer. PHY and MAC air link called primitives under purpose to discover and select the network entry and exit.

The following figure shows end-to-end interoperable network architecture.



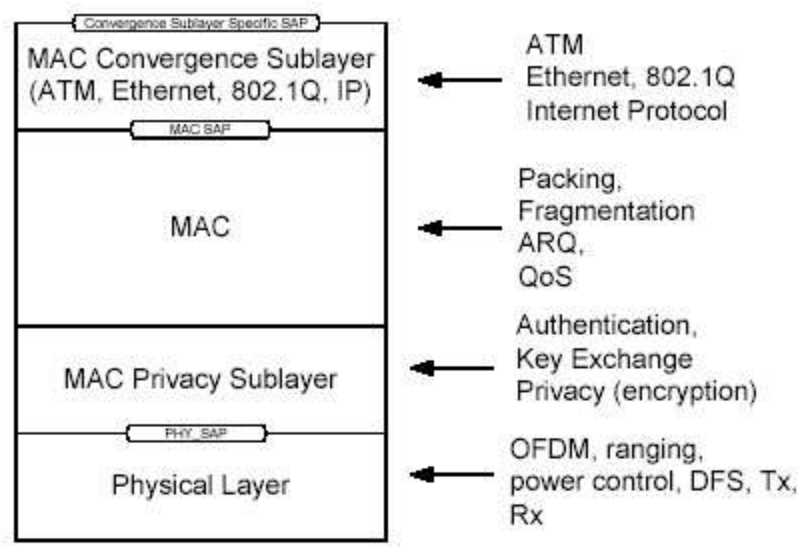


MAC - Medium Access Control

The 802.16 MAC controls access of BS and SS to the air. The 802.16 MAC consist of *Sublayers* which describes how wire line technologies such as Ethernet, ATM and IP are encapsulated on the air interface and how data is classified. An attribute of MAC is that the delivery of communications is secure because it uses key exchange. It supports authentication and encryption, using AES or triple-DES standards during data transfer. Further features of the MAC layer include power saving mechanisms (using *Sleep Mode* and *Idle Mode*) and handover mechanisms.

PHY Layer

802.16e uses flexible OFDMA to carry data, supporting bandwidth for each channel between 1.25 MHz and 20 MHz, with up to 2048 sub-carriers. It supports adaptive coding and modulation, so when there is good signal, a highly efficient 64 QAM coding scheme is used, on the other hand when the signal is poorer, a more robust BPSK coding mechanism is used. Other PHY features include support for Multiple-in Multiple-out (MIMO) antennas in order to provide good NLOS (Non-line-of-sight) characteristics (or higher bandwidth) and it uses error control method combining error detection and forward error correcting coding in other words it is the Hybrid Automatic repeat Request (HARQ) for good error correction performance.



The above figure illustrates the layers of the 802.16 protocols.
These protocols are flexible PHY modulation and coding option, flexible frame and slot allocations, flexible QoS mechanisms, packing fragmentation can be used to deliver broadband voice and data into cells that may have a wide range of properties.
Convergence sub-layers as the MAC enable Ethernet, ATM, TDM voice and IP services to be offered over 802.16.

Relationship between the scope of WiMAX NWG and IEE 802.16.

It is adapted from "All IP Network Architecture for Mobile WiMAX", IEEE Communication Magazine. NWG (Network Working Group).

All-IP architecture will enhance the WIMAX Network features of end-to-end (ETE) for a wide range of IP services. Principles of Network design are in the follow.

4G System Characteristics. There are new challenges and requirements for 4G system such as limited spectrum. Spectrum has constrained resource and the graduated cellular access nodes accommodate it and it should be flexible regarding operator types (independent).

Another challenge is to support different topologies, taking into consideration scale to demand and system cost. The infrastructure could be either fully flat or partially centralized or fully centralized. Access network architecture is flexible and can accept future innovations without requiring significant redesign.

Wide range of services can be offered in 4G radio access technologies. Take advantage significant architectural features like IP services and broadband; it shall generate new capabilities of delivering services. These services could be from real time up to non-real-time and from unicast to multicast. Radio resource management and QoS based on these advanced capabilities.

WiMAx architecture based on a Network Reference Model (NRM), which shall be composed by three sections: Network Access Provider, visited Network Service Provider and Home Network Service provider.

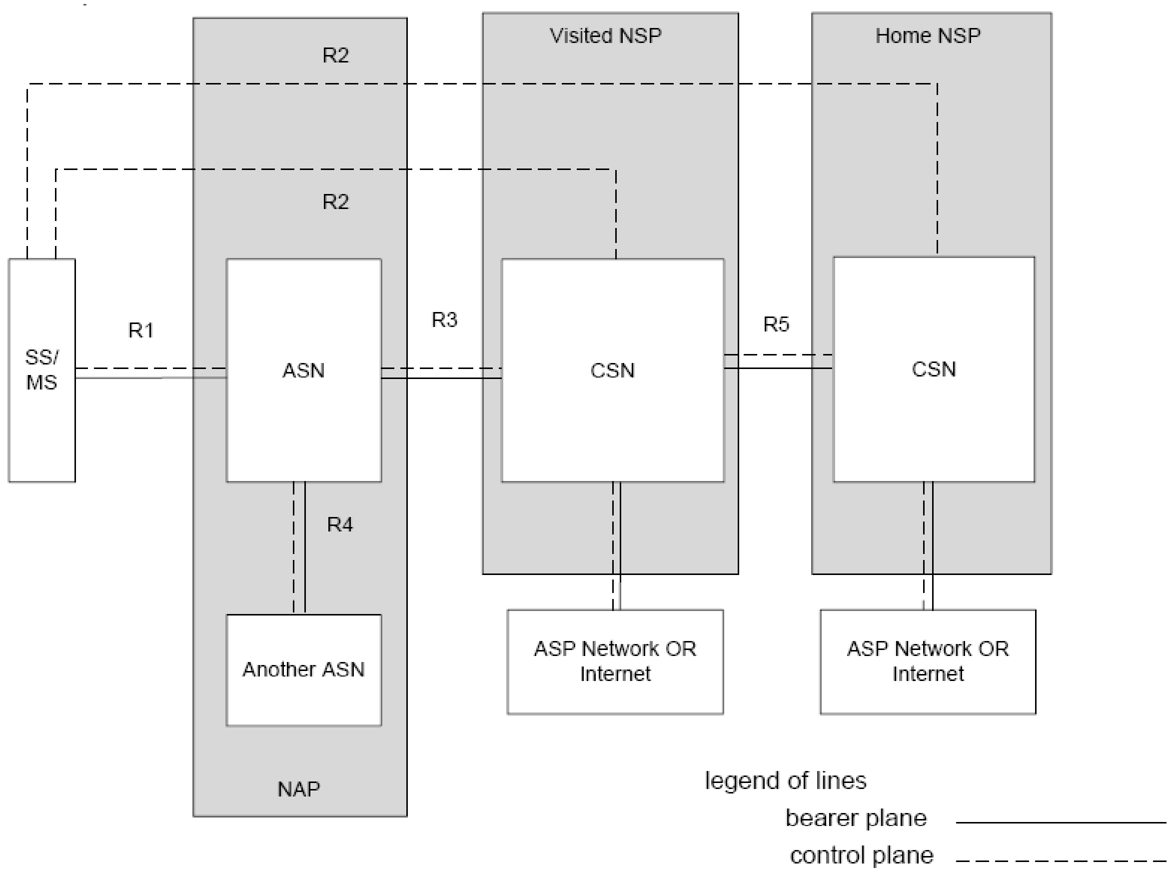


Figure Network Reference Model

It is adapted from “All IP Network Architecture for Mobile WiMAX”, IEEE Communication Magazine.

NRM identifies key functional entities such as Connectivity Service Network (CSN) and Access Service Network (ASN). There are reference points over which a network interoperability framework is defined.

These reference points are :

R1: Reference point between MS and BS

R2: Reference point between MS and ASN-GW or CSN: logical interface used for authentication, authorization, IP host configuration and mobility management.

R3: Reference point between ASN and CSN: supports AAA, policy enforcement, and mobility – management capabilities. Implements tunnel between ASN and CSN.

R4: Reference point between ASN and ASN: used for MS mobility across ASNs.

R5: Reference point between CSN and CSN: used for internetworking between home and visited network.

R6: Reference point between BS and ASN: implements intra-ASN tunnels and used for control plane signaling.

R7: Reference point between data and control plane in ASN-GW: used for coordination between data and control plane in ASN-GW.
R8: Reference point between BS and BS: used for fast and seamless handover.

Principles for WiMAX network

Access Service Network (ASN) is the area of entry point for WiMAX Main Station (MS). The best option is ASN using IP services. ASN offers services with advanced, adaptive modulation and coding schemes, Forward Error Correction (FEC) schemes (encoding IDs 128 and 129 bit of bulk delivery in TCP protocol), flexible UL/DL channel allocation and advanced antenna systems. All these elements optimize interconnection in Access Network and IP play the way of inter-operability of services.

Connectivity Service is applied for two or more operators through broadband IP services over ASN (Access Service Network). Access technologies based on open Industry standard IP protocols obtaining interoperability, seamless access and mobility within ASN. Interoperability based on protocols and procedures. Multivendor interoperability deals with end to end services such as IP connectivity, session management, Quality of Service and mobility for this reason all used protocols should be open.

ASN mandatory supports the following network functions:

- Network discovery and selection of the preferred Connectivity Service Network (CSN) / Network Service Provider (NSP),
- Network entry with Layer-2 (L2) connectivity with a MS (802.16), and transfer of AAA messages to WiMAX subscriber's home network for authentication, authorization and session accounting for subscriber sessions,
- Relay function for IP Connectivity (IP address allocation),
- Radio Resource Management,
- Multicast and Broadcast Control,
- Intra-ASN mobility,
- Foreign agent functionality for Inter-ASN mobility
- Paging and Location Management,
- Accounting assistance,
- Data forwarding,
- Service flow authorization,
- Quality-of-Service,
- Admission Control & Policing.

Connectivity Service Network (CSN): CSN provides IP connectivity services to the WiMAX subscriber(s) between different operators. A CSN consists of a set of several network elements such as routers, proxy/servers (AAA), user databases and Interworking gateway devices.
Each of the following functions identified within a logical entity may be realized in a single physical device or distributed over multiple physical devices

- IP address and endpoint parameter allocation for user sessions,
- Internet access,
- AAA applications,
- Policy and Admission Control based on user subscription profiles,
- ASN-CSN tunneling support,
- WiMAX subscriber billing and inter-operator settlement,
- Inter-CSN tunneling for roaming,
- Inter-ASN mobility,

Connectivity to WiMAX services such as IP multimedia services (IMS), location based services, peer-to-peer services and provisioning.
Base Station (BS): It is one of logical and primary entity of ASN – it represents one sector with one frequency assignment in deployment of network. A BS may be logically connected to more than one ASN Gateway to enable load balancing and redundancy and associated with specific functions such as downlink and uplink scheduler.
ASN Gateway (ASN-GW): Logical aggregation entity that controls plane functional entities. Bearer routing or bridging functions also are performed by ASN-GW.

In mobile WiMAX, Mobile Station (MS) works with two power save modes, the "Idle mode" and the "sleep mode" . These modes are used to minimizing MS power consumption and maximizing the battery life is an important aspect of a mobile technology. The WiMAX network is designed in order to have effective functional state transitions.
The MS has two registered state micro states, "awake" and "sleep". In the "awake" state, the MS has active connections and is transmitting and/or receiving data on these connections. The sleep functions are specific to the air link only, it is like power off and there is no impact on the network elements. For long inactive period, the MS may elect to switch to the "awake" or "sleep". Handovers occur during the "awake" state. Before idle mode, the context of this MS may be stored in the network, so as to enable fast switchback from the "sleep" state to the "awake" state.

Mobility management requires achieving minimal handover latency and packet loss. The 802.16 standard specifies the over-the-air messaging and procedures for handovers. To handle the network side of mobility should be based on the above specifications.
How can ASN – CSN procedure complete a handover? a mobile client acquires a report from neighbouring base stations and send it back to the serving base station, during a handover.

Mobile IP, WiMAX specific protocols provide flexibility in handling mobility. For example our Mobile IP and a given MS consider as Home Agent (HA) resides in a CSN and one or more Foreign Agents (FA) resides in each ASN. Data for this MS is transported through the Mobile IP tunnel which is secured and terminated at a Foreign Agents in an ASN. Data Path Functions (DPF) used to take over and transport the data from the FA to the serving base station, to which the MS is attached. Handover is designed to have multiple levels of anchoring for the user data plane path.
The above functions of ASN and CSN support more advanced IP services such as, Location Based Services, Broadcast and Multicast services for multimedia traffic, IMS and commercial VoIP applications.

3. Admission Control and Interference-Aware Scheduling in Multi-hop WiMAX Networks (Efficient algorithm for scheduling the packet flow)

WiMAX technology provides high-speed wireless broadband access either with multi-hop or single- hop relay. It is a significant technology because through broadband access can pass advanced services like Quality of Services, steaming voice and video etc.

This architecture of WiMAX network uses multiply links which can interfere with each other. In this point efficient algorithm is used in order to schedule the packet flow between cells. There are few features or sub channels which play significant role and there is priority of them according to Quality of Service.

There are two mess modes a single hop mode and multi hop mode. In first case Base Station BS communicates directly with Subscriber Stations (SSs). In the second mode, the SSs can communicate with each other and with BS through multiple hops. A third mess mode is mobile multi-hop relay (MMR). In this case, a relay station RS is inserted in the network between BS and SS. Here, once again, the Quality of Service plays important role in streaming of audio and video. There are service classes of QoS, which define latency, rates and jitter. Service classes are the following: Unsolicited Grant Service (UGS), Real-time Polling Service (rtPS), Enchanched Real-time Polling Service (ertPS), Non Real-time Polling Service (nrtPS) and Best Effort (BE).

QoS defines the priority of task flows that means the packet loss has the highest priority. It gives priority in the latency or bandwidth or jitter. In the following paragraph will outline the scheduling mechanism and admission control.

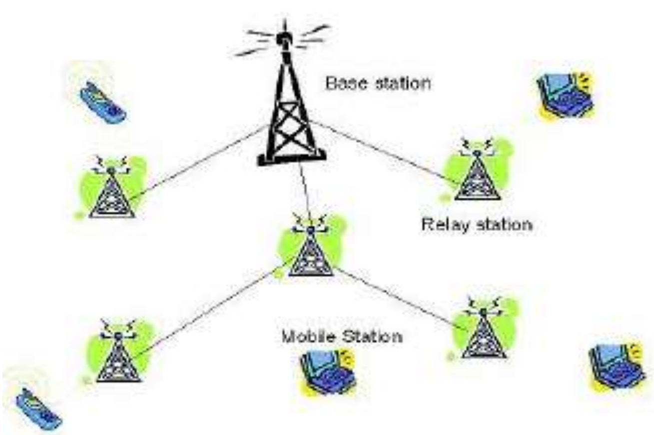
Schedule flow can be in such manner in order to fulfil requirements, in accordance with scheduling algorithm. In this case the efficient spatial can be reused by algorithm in non interfering links. This algorithm runs into two phases in order to allocate free slots (time slot - sub channels) taking the maximum bandwidth requirement. If there are not enough time slots the second phase comes to allocate the minimum bandwidth requirement.

Schedule Efficiency (SE) can be justified comparing different flow scheduling algorithms. Service class priority is taken into account and minimum bandwidth requirement is allocated.

We can define several variants of algorithm and compare their results. The major of them are the total bandwidth allocated, fraction of accepted flows and computation time. Here we justify the necessary of admission control. The schedule flow sub channel "SFS" algorithm is considered that it is better in schedule efficiency, computation time and guaranteed rate, than other five scheduling algorithm.

Network Model

A network model consists of one BS base station and several subscriber stations or RS relay stations. However, small number of hops is always preferable. The topology of the network has tree shape like the following:



It is adapted from "Admission Control and Interference-Aware Scheduling in Multi-hop WiMAX Networks", IEEE 1-4244-1455-5/07.

The transmission in physical layer uses Orthogonal Frequency Division Multiple Access (OFDMA) which divides a channel into a number of sub carriers. The subcarriers can be grouped together into “subchannels”. Consequently, OFDMA works into two dimensions and thus combines frequency domain and time domain access.

Our network model nodes is possible to work in half duplex that mean they can’t transmit and receive at the same time. Thus we have adopted even – odd label regarding links (ex. there is odd link transmit in an odd timeslot). Each flow and each link have its (ID) in order to be scheduled and be routed in access network. There is a time slot within a frame of the link which the link must be scheduled so that the flow reaches the destination by its deadline and we can calculate start time slot for UGS, ertPS and rtPS classes of QoS.

The start time slot (ts) of a link can be defined as:

$$ts = \frac{d - fs - kt1}{t2}$$

d is the deadline, fs is the start of the next frame, k is the number of hops to the destination, $t1$ is the propagation delay and $t2$ is the period of each time slot.

We want to admit and schedule the flows so that the maximum rate and minimum latency requirements, for this problem we purpose heuristic algorithm as solution.

We want to calculate how many flows can schedule in each period. A scheduling period consists of an integral number of frames and each frame includes a number of time slots which are allocated for each subscriber station.

First, the algorithm 1 “SFS” finds out the free time slots and sub channels for maximum bandwidth that can be allocated to all the links of the flow. In this case, there is a different of allocated slots between less bandwidth requirements than maximum bandwidth, these extra time slots – sub channels can be pre-empted for other flows, if it is required. Otherwise, the cases when the bandwidth requirement needs more time slots than bandwidth assigned thus we need an extra schedule flow which will discover these tagged slots and allocate them for this link.

This interference happens when one node receives or transmit from/to two other nodes simultaneously (at the same time slot).

Table 2 - Scheduling algorithm 1.

```
for each flow f in F do
    bwAlloc = SFS() or Timeslot-1() or Timeslot-2();
    if bwAlloc < min bandwidth requirement of f then
        Scheduled = ScheduleFlowExtra();
    end
    if bwAlloc > min bw or Scheduled is TRUE then
        Tag Extra slots;
        Make Temporary Schedule Permanent;
        Update bandwidth allocated to flow;
        accept flow f;
    else
        reject flow f;
    end
end
```

Another algorithm is called "naïve" which is also interference aware. It schedules flows simply calculating the start of the frame and allocates the minimum number of slots which are required. So there are not tagged slots / extra slots and there is only one case. The naïve algorithm allocates free sub channel for flow and if there isn't available sub channel then it proceeds to the next time slot.

Table 3 - Naïve algorithm.

```
for all links l in f do
    slotsalloc = 0;
    finalslot = starttimeslot of link l;
    Ts = startOfFrame;
    subchannelCtr = 0;
    while (Ts <= finalslot) and (slotsalloc < minslots) do
        if subchannel[subchannelCtr] is free then
            slotsalloc++;
            update tempschedule;
        end
        subchannelCtr++;
        if subchannelCtr = MAXSUBCHANNELS then
            subchannelCtr = 0;
            Ts = Ts+2;
        end
    end
    if slotsalloc < minslots then
        Scheduled = FALSE;
        return Scheduled
    end
end
Scheduled = TRUE;
return Scheduled
```

Schedule Efficiency.

We want to have the maximum admission regarding the total attempts and that calculate from schedule efficiency (SE) which evaluate scheduling algorithms.

$$SE = \frac{Ca}{Ct}$$

Where the script a and t in Ca and Ct refer to admitted and total flows, respectively.

Where C is the total of Weight of flows of class multiply their bandwidth of flows.

C = S (Wi * bWi).

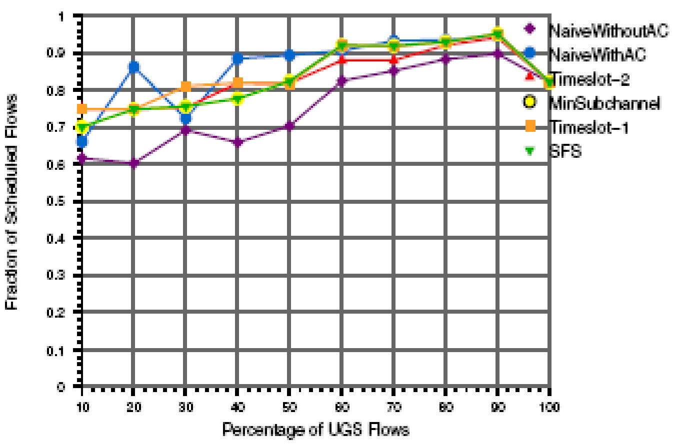
Simulation Results

We use a custom simulator with purpose to generate flows and run scheduling mechanism. We can select between dynamic and static flow however we use static scheduling in order to evaluate algorithms. The flows are generated according to Poisson arrival process. When we use limited number of flows the minimum bandwidth requirements matches the maximum bandwidth requirements. The type of flows generated randomly and each class is associated with a different latency and bandwidth range. We use fixed topology in order to eliminate outside factors between source and destination. We used 5ms for frame size and 256 sub channel which is a basic or typical rate. The priority is UGS class up to BE lowest.

For simulation, the following algorithms have been used: Scheduling Flow Sub channel (SFS), time slot allocate 1 and 2 and naïve. We look through few parameters regarding algorithms like fraction of accepted flows which illustrates the effect of submission control. It measures how many accepted flows per total number of flows, but this factor doesn't take bandwidth into account. All algorithms have shown almost the same effective of the classes. Admission control increases the fraction of accepted flows in UGS, rtPs and ertPS however also BE class could have accepted many flows if there was efficient bandwidth.

Another factor is Schedule Efficiency (SE) which measures the total minimum required bandwidth of flows accepted per total minimum required bandwidth of all scheduled flows. It gives maximum values in SFS algorithm and it can allocate bandwidth efficiently and with priority to the higher service class. Other algorithms give curves close to SFS.

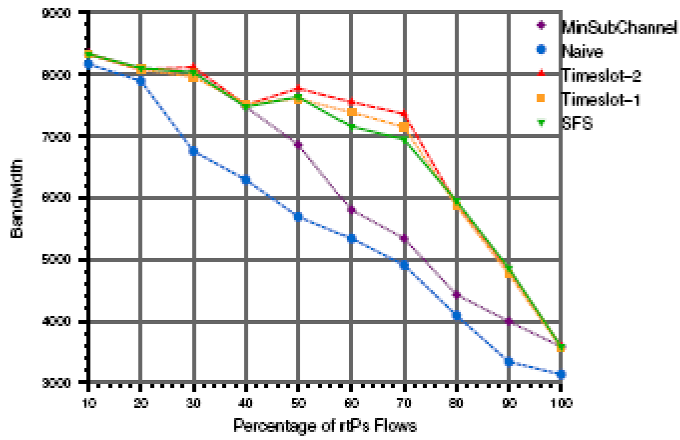
Next figure shows Effect of Admission Control and Scheduling, vary percentage of UGS flows.



It is adapted from "Admission Control and Interference-Aware Scheduling in Multi-hop WiMAX Networks", IEEE 1-4244-1455-5/07.

Bandwidth allocated is the third parameter which compares the total bandwidth allocated to all the accepted flows. It is not the same as the total minimum required bandwidth of all flows because all algorithms exept naïve allocate more than minimum required bandwidth. SFS gives highest results and all the there are not far from SFS with lower performance presented by Naïve algorithm.

The following figure shows the bandwidth utilization with varying percentage of rtPS flow.



It is adapted from “Admission Control and Interference-Aware Scheduling in Multi-hop WiMAX Networks”, IEEE 1-4244-1455-5/07.

SFS and timeslot algorithm have shown better performance than the others in almost all scenarios.
There is another parameter: Computation time is the time which scheduling algorithm needs to execute the program. Flow sets with vary number of total flows following mix uniformly distributed have been generated. Naïve and Min Sub channel algorithm executed with lowest computation time. SFS algorithm time increases linearly with the number of flows but has presented higher bandwidth utilization. Time slots -1 algorithm was inefficiency because need additional time to revisit multiple times each time slot. Timeslot -2 is even more inefficient since it calculates the possibility of the same sub channel is free.

From simulation results we can conclude the SFS is bandwidth efficient and can schedule a larger number of higher priority than Naïve algorithm. However SFS is able to schedule less BE flows than Naïve because naïve uses the minimum bandwidth requirement.

All above algorithm uses centralized scheduling and guarantee collision free schedules. SFS and timeslots maximize allocate extra bandwidth and perform pre-emption if required. SFS is the best in Schedule Efficiency and computation time and it is more efficient in scheduling delay sensitive flows.

4. Multicast Broadcast Services Support in OFDMA-Based WiMAX Systems

Broadband wireless networks can transmit Multimedia stream service using IP network architecture which is an emerge technology with reliable high throughput. Mobile WiMAX bases on Orthogonal Frequency Division Multiplexing Access (OFDMA) and it is the vehicle in broadband transmission. WiMAX operates with MAC layer provides various services among different traffic categories with individual QoS requirements.

WiMAX will be offer multimedia (MBMS) through multicast and broadcast service (MBS). This architecture (MBS) overcomes the shortcoming of limited video broadcast performance, supporting better mobility and offering higher power efficiency.

Multimedia over MBS can support useful applications like mobile TV and IP radio broadcasting which are of the faster growing applications. It is one of the most promising technologies because mobile interoperability can offer scalability in radio access, providing important flexibility in services and deployment options. Mobile WiMAX, through all-IP core network architecture enables convergence between mobile and fixed broadband networks.

Mobile WiMAX supports high data rate transmission via multiple input / multiple output using sub channelization, adaptive coding, and modulation. Multicast Broadcast Service can be combined with the features of digital video broadcast, using orthogonal frequency division multiplex access (OFDMA). It offers possibility to improve system performance in non-line-of-sight (NLOS) environments.

The supported features of mobile WiMAX air interface are: low power consumption at the MS/SS (Mobile Station / Subscriber Station), sub channel (in time division) to provide services in multi channel broadcast, high data rate and large coverage, data casting for streaming audio and video. Flexible radio resources allocate in two modes: full or partial allocation via MBS dynamically and high macro-diversity gains using single frequency network mode (SFN).

The contents of initial MBS service can be delivered over the mobile WiMAX air interface. The Multicast Broadcast Service can be transferred either via separate MBS zone in the downlink frame for unicast service or via dedicated frame to MBS for broadcast service. MBS mode can use SFN operation with flexible duration of zones permits scalability of radio resources. WiMAX supports embedded MBS provides broad range of applications through unicast service.

OFDMA

OFDM is a multiple modulation technique and OFDMA is a multiple access entity. OFDMA consists of sub-carriers which reaching up to 4096, with contribution of fast Fourier transformation so it is further dividing into sub-channels. MAP (Media Access Protocol) messages assign each subscriber to sub-channels. OFDMA supports smart antenna technologies performing vector – flat sub-carriers.

Smart antenna enlarges cell coverage through beam forming. A beam forming single carrier algorithm (vector) runs and calculates the acquisition coverage of smart antenna exploits free spaces of antenna. Physical layer of WiMAX supports Time Division Duplex (TDD) mode and Frequency Division Duplex (FDD) mode simultaneously. WiMAX can support also, other modulations like QPSK, CC, CTC, STBC and SM (see list of abbreviations).

There is a specific region allocated by BS (Base Station) in download frame for MBS services. Each connection has primary Connection Identifier (CID) and security association (SA) which were carried into MBS data. Moreover, there is a DL- MAP (downlink – MAP) which confirms each BS in

MBS zone, first indicates the locations of the MBS packets and after that it informs the MS and SS for the next MBS packet. Every connection in WiMAX between BS and SS / MS has its CID and SA.

MBMS (Multimedia Broadcast / Multicast Service) transmits packets from Point to Multiple endpoints and it uses Multicast CID (MCID). Mobile Station (MS) is not required to be registered to any BS when they belong to the same MBS zone (the same multimedia stream transmission), so MS can move within the MBS zone while receiving the MBS packets without any problem.

MCID (Multicast Connection Identifier) and IP address is used for routing protocol between MS and MBS-GW (MBS gateway) and MBSC (MBS Controller).

MBM Services.

MBMS improves its efficiency through broadcast multicast service centre (BMSC). BMSC provides new features for new user services like membership, session and transmission, proxy and transport, service announcements (it provides channels and programs like news and movie channel to users via logical channel ID) and security – subscriber authentication.

In the proposed architecture there are two functions for MS/SS service discovery delivery and service subscription. In the first function, the users receive information on the forthcoming and on going MBS content. The second service is related on the sub channels. Except MBSC there is an Access Service Network (ASN) consist of a BS and ASN-GW gateway which supports IP multicast routing protocols in order to communicate with MS/SS. There is an MBS source which provides applications such as real-time multimedia and non real time download for store and play usage like sports events and weather reports.

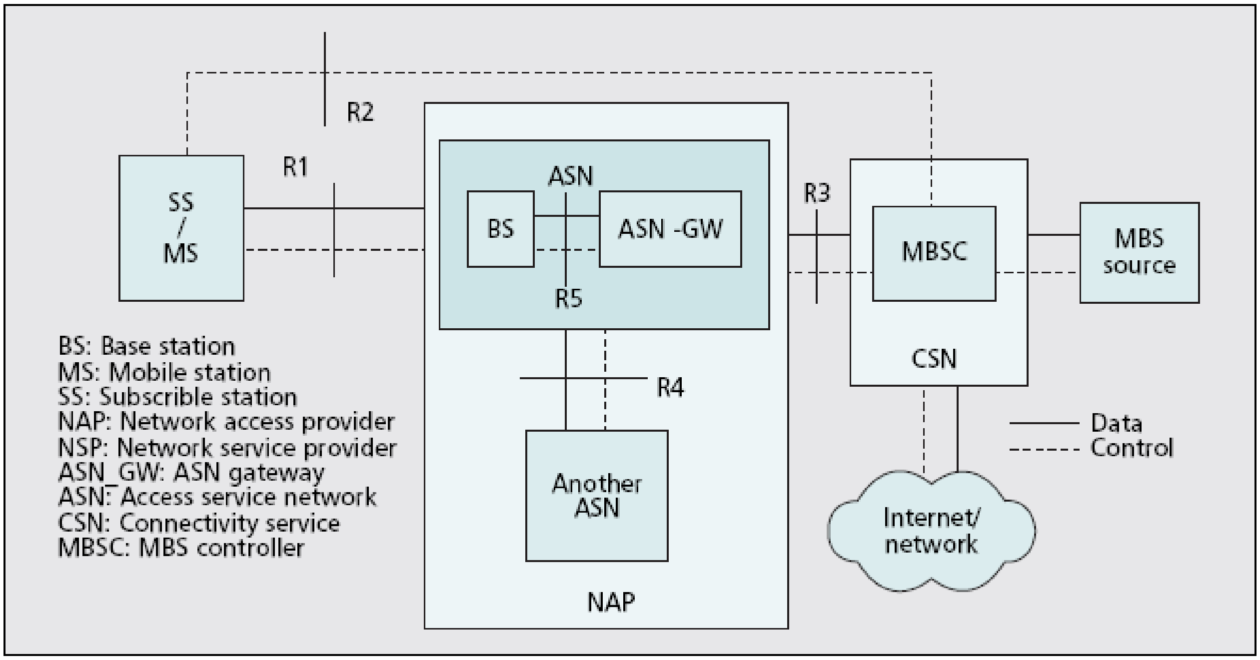
Network Architecture Requirements

MBS is a primary requirement for mobile WiMAX network. Architecture and protocols should be designed in order to meet the following:

- Multicast and broadcast frameworks can be reused in maximum.
- MAC medium access control and PHY layer should be defined, optimizing radio specific features and messages,
- They have to follow open mobile alliance at the application layer complying and interworking with broadcast architecture.
- They have to allow radio resources sharing between broadcast, multicast and unicast transmissions,
- They have to support flexible and dynamic allocation of the transmission zones also, multiple priority level for MBS.
- They can enable MBS sessions and multiple active unicast sessions and various multimedia streams,
- Effective services should also be enabled for discover /information acquisition, selection and authorization,
- They have to support QoS for real-time multimedia applications,

- They have to enable MBS delivery in cases of MS/SS power saving or idle states,
- They have to support security of MBS content through application level encryption.
- Accounting and charging volumes should be implied on each of contents and thus MBS statistical data should also be available.

The following figure is a proposed MBS architecture for mobile WiMAX.



It is adapted from "Multicast Broadcast Services Support in OFDMA-Based WiMAX Systems", IEEE Communication Magazine 0163-6804/07.

Security: MBSC is responsible for creating, maintaining and distributing a cryptographic key for each MBS program in order to keep integrity and confidentiality of MBS contents over the air interface, at R1, R2 and R3.

Synchronization

It is necessary to exist synchronization between MBS and multi BS. That means the same video content is transmitted in the same Time Division Duplex (TDD) frame and in the same OFDMA data region using the same CCS (channel coding scheme), otherwise video data packet could be lost during transmission from MBS controller to some BS. Under this way –synchronization - there are the following goals: ensuring smooth handoff, achieving macro diversity and reducing interference.

There is an error protection beyond PHY / MAC layer for shadow fading, temporal fading or other interferences.

CCS - Channel coding scheme is becoming more robust if there are unequal error protections in PHY layer.

Another significant issue is the overhead of real time transport protocol (RTP)/UDP/IP which limit the video broadcast performance. Three entities are proposed:

a) MBS server which provides encoding and transcoding functions via mapping the video channel identification to CID, for video and RTP.

b) MBS client which consists of a video channel switcher, a video decoder and MBS transport sublayer and

c) The communication entity which MBS coder and decoder use Reed Solomon outer coding. Reed Solomon outer coding and Convolution Turbo Code (CTC) inner coding reduce the video frame error rate without using too much overhead.

WiMAX MBS architecture can conserve energy because it supports sleep and idle modes to enable power saving MS operation.

WiMAX coverage performance depends on transmission power, cell size and duration of cyclic prefix. For example when it operates in 2500 MHz carrier frequency, 1/8 ciclic prefix and 20 W in 19 cells there is 95.5 % of mobile WiMAX coverage with packet error rate lower than 1%.

5. Relay Station Placement in IEEE 802.16j Dual-Relay MMR Networks

RS can bring a revolution in wireless network technology. An advanced coding scheme joining RSs we can enhance the coverage area and capacity by spatial diversity. The aim is to explore the benefits of adopting relay stations (RSs) like to reduce the cost of RS placement. Using the new architecture, the users through dual relay - two active RSs - are connected to the BS. The users could be either mobile stations (MSs) or the fixed subscriber stations (SSs).

Under this design – dual relay – the system offers significant benefits like higher throughput, seamless intra-cell handoff among RSs, robustness in fading channel, power saving and better fault tolerance. There are no only advantages but there is a placement problem which should be solved. The solution could find if we use two face algorithms to deal with the no linearity and NP formulation. Our model consists of two RS with 4 nodes model. The achievable rate in mobile and fixed Relay are correspondence R^m and R^f.

$$R^m = \min[C(\frac{g_{s1}P_s}{N}), C(\frac{g_{s2}P_s}{N}), C(\frac{g_{1d}P_1 + g_{2d}P_2 + g_{sd}P_s}{N})]$$

$$R^f = \min[C(\frac{g_{s1}P_s}{N}), C(\frac{g_{s2}P_s}{N}), C(\frac{(\sqrt{g_{1d}P_1} + \sqrt{g_{2d}P_2})^2 + g_{sd}P_s}{N})]$$

where *Pi* is the transmit power of node *i*, *N* is the power of the background noise, *C*(.) is the Shannon function such that $C(x) = B \log(1 + x)(x \geq 0)$, with *B* as the channel bandwidth, and *gi j* is the channel gain between node *i* and *j* such that $g_{ij} = GL^{-\alpha}_{ij}$, and *Li j* is the distance between node *i* and *j*.

Here, there is a propose framework approach of solution when evaluate the performance gain using numerical analysis. The promising solution considered the mobile Multi-hop Relay network combined with RS which is deployed in a standard point to multipoint mode operation offering a new scheme which a more competitive and applicable for the future MAN. This scenario increases the overall system capacity beating higher transfer rate and generate applications such as Internet Protocol Television (IPTV).

Cooperative RSs in a mobile multi hop relay architecture in a communication network called as dual-relay mode. These RSs cooperate with Base station making an antenna array. It is an advantage against direct transmission with unique features of single relay because dual relay mode offers higher throughput data transmission rate and at the same time improves the performance gain. Two cooperative RSs can cover better the edges of cells without occur disruption due to user mobility. So it minimizes the risk of service discontinuation. Another step is that this architecture – dual relay provides robustness system in cases of fading channel having greater fault tolerance than single relay link. Another advantage of this mode is the power saving. Due to it obtains better fault tolerance it presents better resistance to channel fluctuation consuming fewer power.

In dual relay mode we want to minimize the number of RSs having the optimal locations. In this transmission mode the wireless connections comes from the Mobile Stations and from fixed Subscriber Stations so we will be careful for the placement of RSs which is vital for the infrastructure operators. We have to find the optimal solution of RSs depending on traffic demand. This requirement is formulated into a Dual RS Placement problem solving when developed in two phase heuristic.

6. On the Analysis of Using 802.16e WiMAX for Point-to-Point Wireless Backhaul

It analyzes the capacity and overhead for Microwave Access WiMAX as backhaul transport. It scrutinises the overhead size and downlink and uplink capacity, an Enhanced Variable Rate Codec (EVRC) VoIP bearer traffic efficiency.

Subscribers use more mobile minutes and richer data applications, consequently it is expected to see greater need for backhaul services and the trend will just continue as more and more operators deploy 4G and WiMAX network globally. It is estimated that 1,8 million Base Station have been deployed in 2006 globally and 2010 there are more than 3,6 million BS. Backhaul network not only transports E1 leased lines but mobile wireless subscribes which will be the major segment of subscribers.

Point to Point (PTP) is the only category which can be used to wireless backhaul technology, employs high gain directional antenna. So there is extended transmission range and reduction to interference. PTP micro wave system which is the dominant in wireless carriers technology uses PDH / SDH microwave radio running at 6 GHz to 38 GHz. Radios above 6 GHz come with restrict Line of Sight (LoS) requirements and the license of band radio is relative expensive and incur increased CAPEX (Capital Expenses). These technologies promise operation in sub 6 GHz spectrum and Near LoS or Non LoS operations.

WiMAX will be examined as backhaul overhead. Let see its parameters in Physical layer of 802.16e OFDMA.

Table 4 – Parameters in Physical layer

Parameter	Values
System bandwidth (MHz)	5, 10, 20
FFT Size	512/1024/2048
Total OFDMA symbol duration (μs)	100.84
TDD frame duration (incl. TTG+RTG) (ms)	5
Total number of symbols (DL+UL)	49

It is adapted from table 1, “System PHY Parameters” of On the Analysis of Using 802.16e WiMAX for Point to Point Wireless Backhaul.
FFT is transmission speed, TDD time division duration.

Frame Control Header (FCH) size.

When QPSK modulation in rate 1/2 is used, each frame contains FCH which sent in Partial Usage of Sub channel for 4 next subchannels. FCH includes information for Downlink specifies the length of DL_Map message and for the repetition coding. For 5ms duration, FCH needs 192 bits of air interface capacity. DL_Map length is 248 bits when there is very good RF quality otherwise LoS and for backhauling traffic does not require any repetition. We assume four OFDMA DL_Map IE’s for aggregated DL backhaul traffic. The same happen in Up link Map.One channel is required for DL traffic acknowledgement (DL ACK) and one for aggregated UL backhaul traffic. The length of UL_Map is 224 bits for ½ rate UL_Map needs double that means 448 bits air interface UL Phy resource.

DL channels are 8, 16 and 32 for 5 MHz,10 MHz and 20 MHz, respectively. In Full Usage of Sub channels each DL has 96 bits with QPSK, 192 bits with 16 QAM and 288 bits with 64 QAM.

IEEE 802.16e WiMAX has been designed for mobile wireless access.

Its overhead consider large eg. 11,1% in 5 MHz WiMAX system, however the repetition is high (4 or 6) in practical deployment with robust Modulation Code: (QPSK ½ code rate). It was designed to have a Point to Multipoint (PTM) MAC (Medium Access Control) that allows a WiMAX to accommodate multiple mobiles at the same time. In this case, this overhead consider high when

(PTP) Point To Point topology is used for wireless backhaul application. The overhead ratio can be further reduced if QPSK and 4 repetition restriction in the DL_Map and UL_Map can be relaxed. Backhaul link in 64 QAM ¾ code rate can yield an aggregation capacity of 13/57 Mbps in UL /DL respectively for 5 /20MHz. WiMAX 802.16e can provide adequate backhaul transport for 3G/4G access network and PTP microwave backhaul at a lower CAPEX when compared with traditional licensed band.

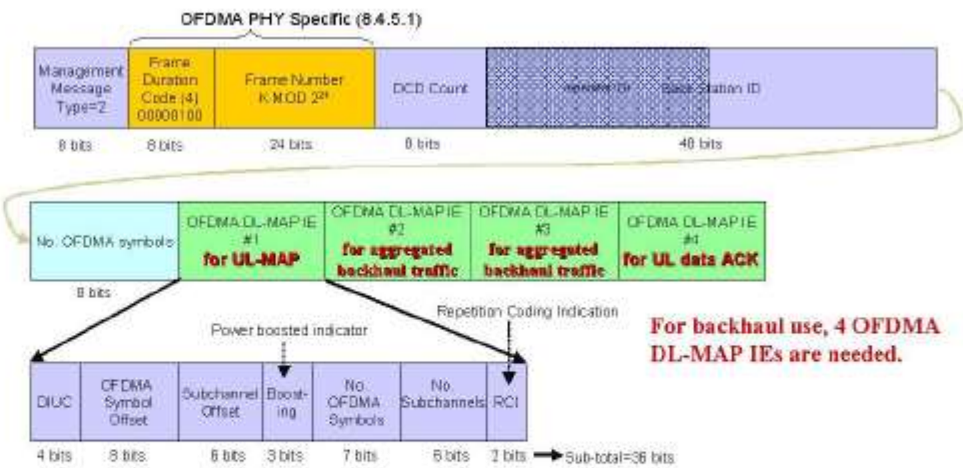
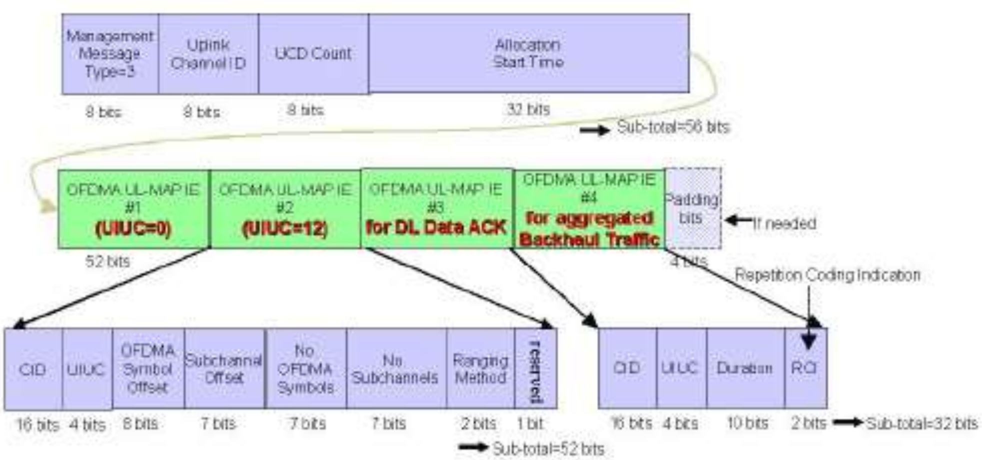


Figure 1 DL-MAP Size for Backhaul Traffic



Total UL-MAP Length = 56 + 1×52 + 1×52 + 2×32 = 224 bits

Figure 2 UL-MAP Size for Backhaul Traffic

It is adapted from figure 2, "WiMAX backhaul Capacity Analysis" of On the Analysis of Using 802.16e WiMAX for Point to Point Wireless Backhaul.

7. Relay Station Technology – SoC

In order to achieve streaming and distribution of media with rich content on the wireless network infrastructure it is needed more service capacity, denser market coverage and increased building penetration. The Relay Station technology bases on highly Integrated System on Chip (SoC) platform. On single silicon design platform, it is able equipment vendors to build indoor and outdoor base stations, required to bring fixed, nomadic and mobile multi-media services to the market. It supports high-density deployment and the high-performance service requirements of future mobile multi-media services.

This platform of integrated SoC consists of more than one microcontrollers (for embedded applications) or programmable microprocessors or digital signal processors (including processor core, memory and programmable input/output peripherals). Additional, a SoC includes of Memory blocks of Ram, ROM, EEPROM and flash. There is timing sources, counter timers, external interfaces such as USB, Ethernet, Firewire and at the end there is Voltage regulator with power management controller.

All of these parts connected together with bus like Advanced System & Peripheral Bus (ASB & APB). They follow Advanced Microprocessor Bus Architecture (AMBA). AMBA defines a framework of multilevel busing system, with a primary system bus and a lower-level peripheral bus. It is divided in two system buses: the AMBA High-Speed Bus (AHB) or the Advanced System Bus (ASB) and the Advanced Peripheral Bus (APB). Competitors of AMBA include IBM's CoreConnect and Silicore's Wishbone bus systems. Different clock rates are used by the SoC's system and peripheral buses. SoC's system and peripheral buses link via a bridge that buffers data and operations between the two buses. The System buses are multimaster, they use a central arbiter, each transfer has an address and control cycle and they're able to start the next transfer's arbitration and address phase while finishing the current transfer.

Each SoC consists of hardware and software that controls microprocessors or microcontrollers. They are capable of running software such as Windows or Linux using external memory chips. The design flow based on emulation (duplicates the system) platform following field programmable gate array (FPGA).

RS system is too complex to fit on just one chip built with a process optimized for just one of the system's tasks, as alternative solution is a System in Package (SiP) comprising a number of chips in a single package. A system-in-a-package, also known as a Chip Stack MCM is a number of integrated circuits (ICs) enclosed in a single package or module.

6. Chapter III - Description of Research Methodology

This project will be able to deliver ubiquitous broadband content and it would provide excellent coverage and increased throughput of the current networks without the costs that installation of new base stations require, since a relay station will play the role of the re transmitter. It should be mentioned that the relay station will not just retransmit the signal, but will include some form of intelligence (e.g. adaptive antennas, change in modulation of received signal, etc.).

Objectives

The whole project has the following objectives:

- To form an optimized architecture for relay based network with well defined partitioning and interface definition between the network elements : Base Station, Relay Station and Subscriber Station.
- To create an interoperability test suit for base station – relay station – mobile station interoperabililty scenarios.
- Lab Architecture Set up
- Lab Test Procedure: Description of tests that will be performed to satisfy the proposed scenarios, services and applications defined in WP2
- Set up the System for Field Testing
- Field Test Procedure: Testing of Relay equipment along with various wireline and wireless field technologies
- Creation of a complete WiMAX relay based on network including:

  Network operator requirements and business case analysis

  Network architecture and system specification

  Development of WiMAX relay beta prototype

  System integration and interoperability of the developed relay product with standard WiMAX base station and subscriber station equipment.

  Lab and field performance testing of the integrated beta prototype relay system

The proposed project examines relay station implementations for WiMAX as this technology is the currently most advanced wireless technology available for deployment, and many of its aspects are likely to be implemented in any 4G wireless technology.

Description of Research Methodologies, Approaches / Methods, Task Definitions and Work Schedule

The whole project is divided into four main groups structured in nine work packages (WP):

Support (WP1, WP9): The first group of work packages encompasses support activities, such as project management and exploitation issues undertaken by the project.

Requirements & Specification (WP2, WP4). The second group of work packages comprises the first part of the core activity within the project. After establishing the system requirements and performing extensive surveys of state-of-the-art technologies, the formal specification of the pursued system will follow.

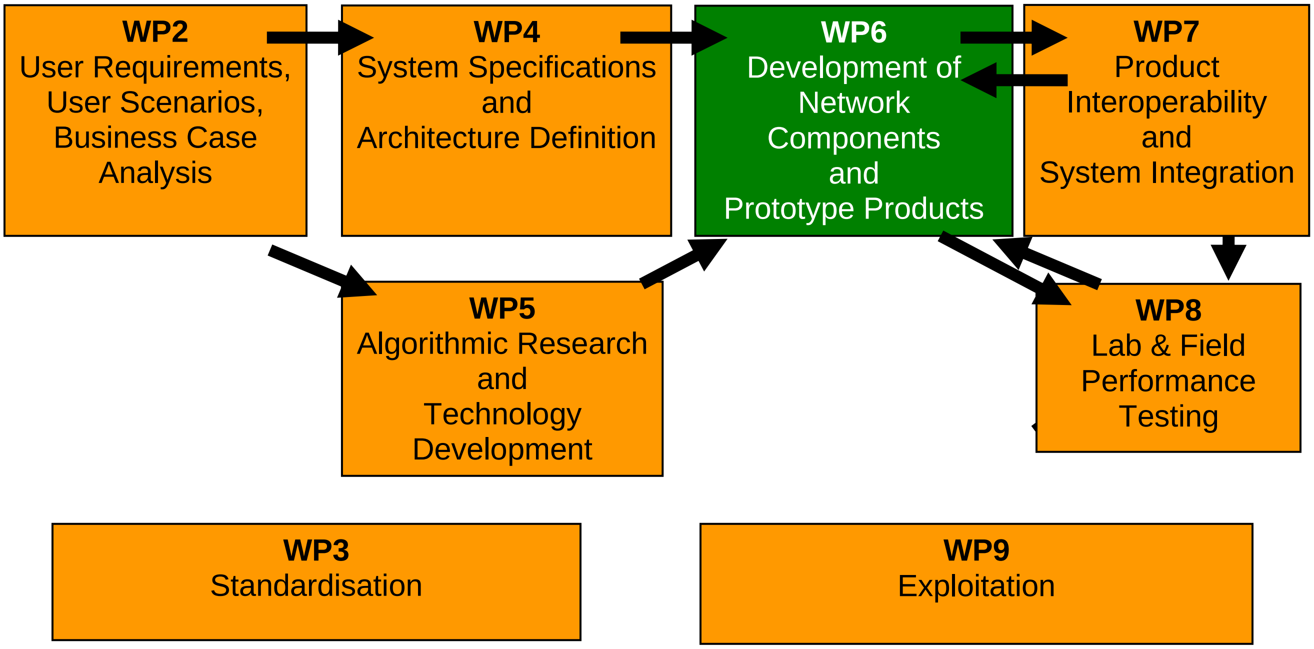
Development (WP5, WP6). The third group of work packages comprises the second part of the core activity within the project. It will employ a feedback model for the system development, so as to refine and update the specification in the course of action, so as to finally deliver flexible and powerful system components.

Integration & Trials (WP7, WP8). In the fourth group of work packages, the project will finalise the built platform by integrating the distinct components in WP7, and perform trials for actual results in WP8.

WP3 is the workpackage referring to contribution to international standardization bodies and is common in the second, third and fourth group.

The following figure shows the relation between Work packages of the project.

Work packages breakdown



We will focus on WP8 which will play the main role in order to extract useful conclusions and to improve the whole system to be realistic.

Tasks and Milestones for WP 8:

- Task 8.1: Laboratory Test Architecture
- Task 8.2: Field Tests

Action Areas are :

- Propagation Simulations
- Laboratory Tests
- Field Tests
- NMS Implementation

Laboratory tests

- Tests to be performed under laboratory conditions
- Areas of Interest:
  - Maximum Performance evaluation
  - Support of RT & Non-RT services
  - QoS/Scheduler Testing (UGS, BE, rtPS, nrtPS)

- Operation of Services to 802.16e clients from various vendors
  - Stability Tests

Laboratory tests - Performance

- Maximum system performance to be tested under laboratory conditions
- Performance metrics to consider:
  - Throughput
  - Delay
  - Jitter
  - Packet Loss
- H/W & S/W performance measurement tools based on Spirent & Ixia measurement equipment

Laboratory tests – Service Support

- Qualitative & Quantitative Tests
- Real Time services (e.g. video, voice) will be executed to mobile terminals
- Various video and audio codecs to be used
- Verify if quality of provided services is within accepted levels (using PESQ, PEVQ, MOS etc)

Laboratory tests – QoS Tests

- Double, Triple play tests
- Tests of simultaneous service support (Data, Voice, Video)
- Service Priority Tests
- MRBS/RS Scheduler Test for simultaneous service support
- Real Time service quality should be the same under load/no-load conditions
-

Laboratory tests - Stability

- Tests with 802.16e clients from various vendors (Performance & QoS)

- Long run tests to verify stability of hardware & software

Field Tests

- Tests will be performed under outdoor environment conditions
- Comparison with initial simulation results
- Areas of Interest:

  - Coverage – Performance

  - Simultaneous user support – Load Tests

  - Compatibility with other field technologies (e.g. wireline infrastructure)

Field Tests –load tests

- Multiple users should be supported by the system
- Subscribers with different profiles (data, voice, both) will be tested simultaneously
- Maximum capacity tests for BS/Relay to prove robustness under commercial deployment conditions

Gantt Chart

The following time table - Gant Chart has almost been put into practice and in past it has been modified many times.

Table 5 – Project Schedule

Task Name	Duration	Start	Finish
Defined the work packages	5 days	07/05/10	12/05/10
Literature review	60 days	14/05/10	4/08/10
Managerial plan and work schedule.	2 days	17/05/10	18/05/10
Set up & Lab tests	15 days	10/09/10	25/09/10
Field Tests	25 days	01/11/10	26/11/10
Relay Station & Wireless system integration report	10 day	28/11/10	08/12/10

The whole Gant Chart is in attached file 1

Risk plan

Risk has three primary components: an event, a probability of occurrence of that event, and the impact of that event. This work aims to identify risk factors and dependencies. More specifically, project uncertainties related to qualitative elements and to quantitative elements will be identified while their probabilities and impacts will be assessed. Furthermore, alternatives will be identified for each of the risk factors.

In any innovative project, because of the interaction and the involvement of new technologies, risks are taken into consideration. To minimize the implementation risks user requirements and system specifications should be standardized or defined in an early stage.

During the specification phase, the minimal set of functionality, which is necessary for the system operation according to the specifications, will be identified. The project will aim at the fast implementation of a working prototype, which will be gradually enhanced with further functionality. This way the potential problems will be detected and encountered on time. The risk is lying on the time with each module is available. The success of the project is highly dependent on the ability of the partners to cooperate at a very meticulous level to avoid delays, deviations from the specifications or reduction of functionality.

The structure of the implementation work package (as described in the above section) attempts to clearly separate the functional modules in a vertical way, thus eliminating any critical interdependencies regarding the implementation effort.

Conclusion The main scientific and technological objectives of our project are in the area of design, development and integration of advanced wireless relay stations based on OFDM technology in order to foster and exemplify the WiMAX technology by delivering to the subscriber broadband multimedia content. It aims to increase the bandwidth and quality of service to the end user. I believe this project is feasible to be achieved.

Research Methods

According to the Methodologies in task1, section e, it is divided into nine work packages (WP):

WP1 WP1 Project Management provides management and overall coordination of activities, risk analysis, planning and control.

WP2 User Requirements, User Scenarios, Business Case Analysis will present as a first step, the contexts that will require the adoption of this new technology, possible limitations of the already existing 802.16 deployments and what are the requirements from a user's perspective in terms of new service capabilities.

WP3 Standardization will include all efforts made for the contribution to the standardization process of relay technology and networks.

WP4 System Specifications, Architecture Definition Following the user requirements and scenarios analysis in WP2, a thorough study and selection of network architecture will be made in this work package.

WP5 Algorithmic research and technology development This workpackage will handle the algorithmic research and technology development, and will be responsible for the design of the novelty S/W and H/W functional areas of the final product.

WP6 Development of Network Components and Prototype Products. Considering that the components of the network elements are thoroughly defined during WP2 and WP4 for desired operation inside the specifications criteria, the development team starts to build the relay station that will be interconnected for the creation of the beta prototype system.

WP7 Product Interoperability and System Integration will enable the operation of the prototype developed in WP6 in already existing networks. An innovative interoperability testing methodology for relay supporting network will be developed followed by a test specification for this Project that can prove both conformance and interoperability to the this Project requirements and specifications delivered in WP2 and WP4.

WP8 Lab and Field Performance Testing will focus on the certification of the proper functionality of our system. During the development process and as the 802.16j matures, this evolution process will enhanced with more complex scenarios and characteristics.

WP9 will_exploit the project results.

The background

Traditional Relay Stations

Relay stations usually have used for shortwave applications and they are transmitter sites used by international broadcasters to extend their coverage to areas that cannot be reached easily from their home state, for example the BBC operates an extensive net of relay stations. A traditional shortwave relay station depends on how many transmitters and antennas that it will have.

General requirements of shortwave relay stations

- Road access (fairly universal)
- HVAC mains access building or transformer in the transmitter building itself
- Staff quarters (if the relay station is not fully automated)
- Incoming audio processing centre, but since the mid 1980s this has evolved into one to five rack units
- Transmitter hall (50 kW, 100 kW, 250 kW, 300 kW, 500 kW transmitter)
- Switch matrix (but these are not typically used by modules)

- Antenna tuners (sometimes called ATUs or roller coasters because of their appearance)
- Feeder lines (coax cable and open feeder lines are the most common feeders in use)

Where the broadcast programs go

- generally to target areas that are more than 300 km from the transmitter site
- most shortwave relay station target areas are 1500 km to 3500 km from the transmitter site

The existing relative projects

Fixed WiMAX which is similar with WiFi but it uses other protocols and Standards.
To achieve a successful broadband wireless access solution, the IEEE 802.16 subcommittee has released a series of standards for WiMAX (worldwide interoperability for microwave access). From a technical viewpoint, WiMAX is a feasible alternative to the wired internet access solutions such as cable modem and DSL. Nevertheless, from the commercial viewpoint, whether the promise of WiMAX will be materialized still depends on its revenue rate to telecom operators and its service quality to the subscribers. There are two resource management mechanisms in WiMAX access networks, that is, adaptive power allocation (APA) and call admission control (CAC), from the perspectives of both service providers and WiMAX subscribers. APA emphasizes how to share the limited power resource of base station among different WiMAX subscribers and further influences the access bandwidth of each subscriber; CAC highlights how to assign a subscriber's access bandwidth to different types of applications. Moreover, to build a WiMAX access network, APA and CAC have to work cooperatively to provide cross-layer resource management. It uses OFDMA-TDD system, which allows high spectrum.
The existing Wi MAX problems are coverage although APA is used and throughput rate uplink and downlink sometimes is low.

802.16e uses scalable OFDMA to carry data, supporting wide bandwidth of frequency between 2 and 66GHz, and rates enhance up to 72 Mbps in the air. However, channel bandwidths could be 3.5 MHz or 5 MHz or7 MHz. WiMAX uses adaptive modulation and coding, it depends on conditions of good signal, density of users per sqkm and of QoS. There are the following modulation which used by WiMAX: QPSK, 16 QAM or 64 QAM. Where the signal is poorer, a more robust BPSK coding mechanism is also can be used.

Topology – Sites

In Greece there are three main region where WiMAX is implemented successfully.

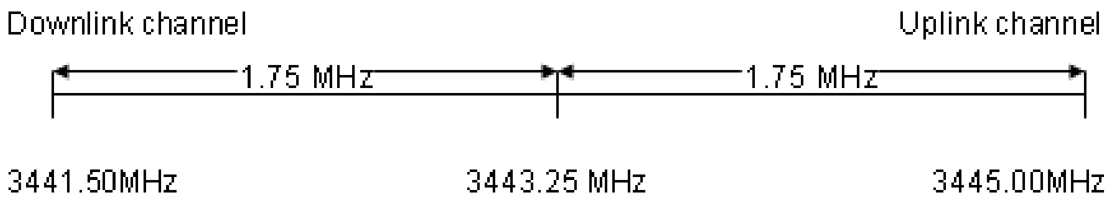
1. Ippokratios Politia –Afidnes area. WiMAX made from Canadian company Redline.

2. Agion Oros – Thessaloniki state. WiMAX made from Apperto company.

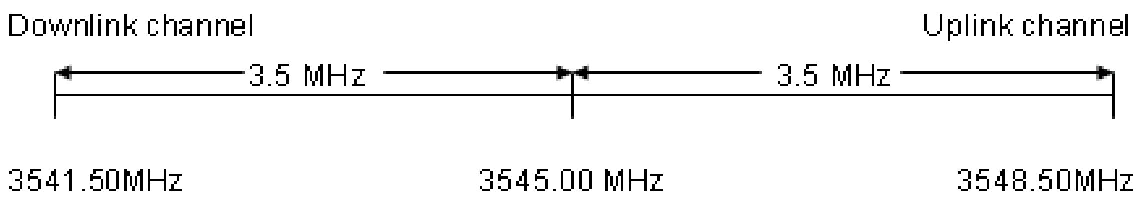
3. Attika. WiMAX made from Canadian company Redline.

Transfers in backhaul and access network use PTP in 7 MHz and PmP in 3,5 MHz mode.

PtP mode:



PmP mode:



Channels could be implemented in all cases but if we want to have better features two cases are preferred:

Transfer of signal can be done in LOS Line of Site without obstacles and in Optical Line of Site – it is out of Fresnel zone. Of course WiMAX can be operated in Non Line of site but then cells should be smaller.

Table 6 - Transfer rate related with modulation:

Modulation	10MHz Channel	3.5 MHz Channel
64QAM ¾	**37.4 Mbps**	**13.1Mbps**
64QAM 2/3	**33.9 Mbps**	**11.6Mbps**
16QAM ¾	**24.9 Mbps**	**8.7Mbps**
16QAM ½	**16.6 Mbps**	**5.8Mbps**
QPSK ¾	**12.5 Mbps**	**4.4Mbps**
QPSK ½	**8.3 Mbps**	**2.9Mbps**
BPSK ½	**4.1 Mbps**	**1.5Mbps**

Encryption

The above WiMAX use triple DES (Data Encryption Standard) in transfer mode between BS and RS of subscriber (CPE). This means the used key has 168 bit length in the air.

In order to increase the security and reduce the traffic between RS and MS, VLAN technology is used in WiMAX.

WiMAX supply the customer with the following services:

Internet (QoS is Best Effort),

VoIP + Fax

Internet + VoIP,

Internet + VoIP + Fax.

Quality of Service is divided in four parts:

Best Effort (BE) - it is appropriate for Internet service because it doesn't give guaranty for bandwidth.

Non –real time Polling Service (nrtPS) - it is suitable for data which they have not fixed length, like FTP.

Real time Polling Service (rtPS) – it is suitable for video without fixed length.

Unsolicited Grant Service (UGS) – it is suitable for real time packets with fixed length, like voice line.

Table 7 – Quality of Service

Service	Definition	Applications	Mandatory QoS Parameters
UGS	Real-time data streams comprising fixed-size data packets issued at periodic intervals	T1/E1, VoIP without Silence Suppression	• Maximum Sustained Traffic Rate = Minimum Reserved Traffic Rate • Maximum Latency • Tolerant Jitter • Request/Transmission Policy
ertPS	Real-time service flows that generate variable-sized data packets on a periodic basis	VoIP with Silence Suppression	• Maximum Sustained Traffic Rate • Minimum Reserved Traffic Rate • Maximum Latency • Request/Transmission Policy
rtPS	Real-time data streams comprising variable-sized data packets that are issued at periodic intervals	MPEG Video	• Minimum Reserved Traffic Rate • Maximum Sustained Traffic Rate • Maximum Latency • Traffic Priority • Request/Transmission Policy
nrtPS	Delay-tolerant data streams comprising variable-sized data packets for which minimum data rate is required	FTP	• Minimum Reserved Traffic Rate • Maximum Sustained Traffic Rate • Traffic Priority • Request/Transmission Policy
BE	Data streams for which no minimum service level is required and therefore may be handled on a space-available basis	HTTP	• Maximum Sustained Traffic Rate • Traffic Priority • Request/Transmission Policy

FP6

FP6 is a recent project that examines aspects such as Smart Antenna (specifically MIMO) and ROMANTIK (Resource management and advanced transceiver algorithms) and both projects were focussed on the integration of these aspects into CDMA based wireless technologies. In our project, our focus will be the implementation of relay architecture and smart antenna technology into OFDMA based WiMAX technology. As there is broad industry consensus regarding the usage of OFDMA technology in beyond 3G wireless networks (like WiMAX, LTE or any other candidate), our project will these concepts several steps further towards the era of 4G wireless. In addition, it includes product build, interoperability and field testing which was not included in former project, hence taking the relay concept beyond the theoretical stage.

The aim of FP6 was to design an architecture that provides seamless QoS support, mobility, security and multicast for a heterogeneous wireless environment. Such environment might be composed of all kinds of network technologies such as fixed and mobile, wired and wireless, unicast and broadcast, ad-hoc and infrastructure mode networks. FP6 does not include bearer technologies. It focuses on higher layers and common interfaces to access technologies. Thus, the scope of both projects is complementary

The FP6 aims to develop a ubiquitous radio system concept for mobile communication systems beyond 3G. The project covers a full scope from short-range to wide-area scenarios. The concept is based on common radio interface technology that adapts to user needs and scenarios by utilising advanced and flexible network topologies, physical layer technologies and frequency sharing methods. In contrary our project will work on pre standard 802.16j to enhance it. Therefore missing functionality is identified, new and innovative solutions are investigated and finally the new features are contributed to the standardisation bodies. The developed enhancements will be utilized by network equipment that implements the new standard amendment. The enhancements might even be leveraged by devices still using legacy protocol stacks. Our project targets at a low cost relay station to be used with the base stations of WiMAX systems.

Equipment

SW applications

Iperf - It is used for throughput measurements.

Iperf is a network testing tool. It creates TCP and UDP data streams and measures the throughput of a network that is carrying them. Iperf measurement tool has been written in C++.
Iperf gives the user the possibility to set various parameters for testing a network, or alternately for optimizing or tuning a network. Iperf can operate as client or server and can measure the throughput between the two ends, either unidirectional or bi-directional. It is open source software and runs on various platforms including Linux, Unix and Windows. Datagram size is flexible to be specified by user in order to provide results for throughput and for packet loss. In TCP mode, Iperf measures the throughput of the payload and the results can be present in Graphical user interface (GUI).

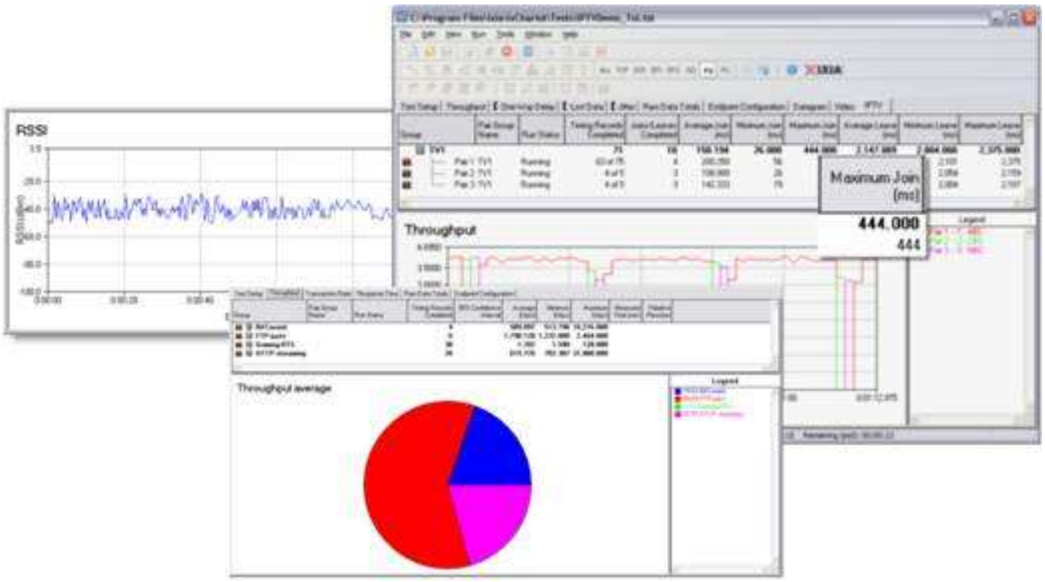
IXchariot - It is used for throughput measurements.

IxChariot is also a test tool for simulating real-world applications to predict device and system performance under realistic load conditions. IxChariot comprise of Console, Performance Endpoints and IxProfile.

IxChariot or Ixia is used to describe high-speed Internet access for end customers, via wireless, cable, or DSL. Ixia can generate traffic in a broadband network. Broadband requires numerous protocols and devices to work together seamlessly to provide reliable customer Internet access, especially when rolling out new services that consume larger and larger amounts of bandwidth. It offers sufficiently testing broadband network protocols, equipment and network topologies. Ixia specializes in testing network components and topologies, helping to ensure broadband reliability. Ixia's platform emulates network protocols and simulates network devices in order to have full monitoring of network topology (even though in Access Node and Home Gateways service), to meet Quality of Service objectives and to verify service level agreement through subscriber session.

IXChariot features

It operates in transport layer (Layer 4), allows user to tailor scripts capabilities using IxProfile and IxChariot's SDK, to create sophisticated traffic patterns with and without QoS for IPv4 and IPv6, to measure throughput, jitter, packet loss, end-to-end delay.



IxChariot GUI

Cellular Expert and MATLAB.

Cellular Expert is a wireless telecommunication network planning which work on GIS platform, offering optimization and data management solution. Cellular Expert allows users to plan, optimize network and analyze information efficiently, to lower costs and improve the quality of customer support services and reporting tasks for radio networks. It use an updated software which supports the latest technologies like WiMAX.

MATLAB stands for "MATrices LABoratory" and is anumerical computing environment and programming language. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++ and Fortran.

Spirent measurement equipment

Spirent measurement equipment is able to move in a cellular network, seamlessly between cells and between radio access technologies (RAT). Spirent’s solutions quantify the mobility and inter-RAT performance of devices and chipsets in the lab under real-world network conditions for GSM/GPRS/EDGE, WCDMA, and HSPA. The 8100 Mobility and inter-RAT solutions provide a controlled environment, reproducing real-life network conditions (under a wide range of handover) for consistent and repeatable test results. Spirent’s 8100 meets a wide range of testing needs: from R&D customers who require flexibility and customization to operator looking for turn-key and fully automated solutions in their acceptance test plan.

It is necessary to emulate dynamic network conditions and behavior in test cases that can scale to the size and complexity of a live network while gathering results that accelerate diagnostics and troubleshooting, so the Spirent equipment is proper for this purpose. It can be used in broadband network.

PESQ, PEVQ and MOS

PESQ *Perceptual Evaluation of Speech Quality*, is applied for objective voice quality testing used by phone manufacturers, network equipment vendors and telecom operators. It is standards for testing methodology of automated assessment of the speech quality. PESQ provides true voice samples as test signals to characterize the listening quality as perceived by users. The information is made available to an algorithm, voice quality test algorithms can be divided into two main categories: A "Full Reference" (FR) algorithm, it can compare each sample of the reference signal to each corresponding sample of the degraded signal (listener side). The second category is "No Reference" (NR) algorithm only uses the degraded signal for the quality estimation and has no information of the original reference signal.

PEVQ *Perceptual Evaluation of Video Quality,* is a standardized end-to-end measurement algorithm in terms of the picture quality of a video presentation by means of a 5-point Mean Opinion Score (MOS). The measurement algorithm analyzes visible artifacts caused by a digital video encoding/decoding process, RF- or IP-based transmission networks and end-user devices. The information is made available to an algorithm, consists of three categories Full reference, Reduced Reference and No reference like in PESQ.

MOS measures the quality of received media after compression and /or transmission, providing numerical indication of the perceived quality of received media after compression and/or transmission. These multimedia services could have compress bandwidth especially when codecs are used. The MOS is expressed as a single number in the range 1 to 5, where 1 is lowest perceived audio quality, and 5 is the highest perceived audio quality measurement.

Prototype Relay Station

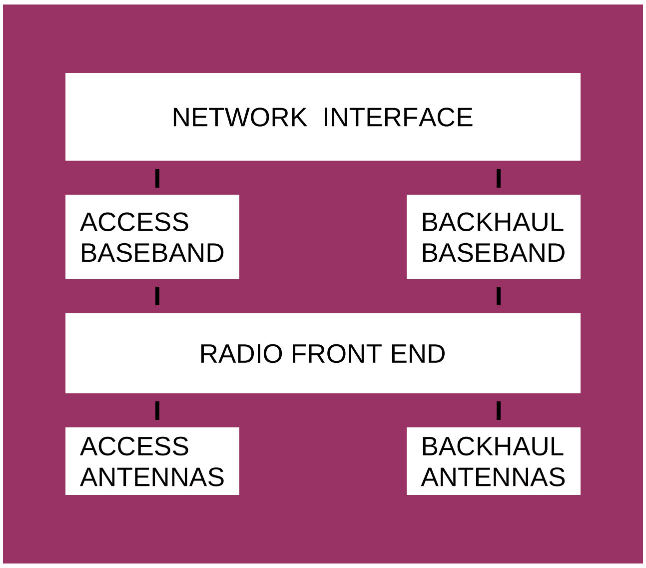
Relay Station could be in two types:

a) Single Unit Relay Station (SURS) which follows the concept of the IEE802.16j Time domain transmit and Receive (TTR) and it enclosed in one unit outdoor or indoor.

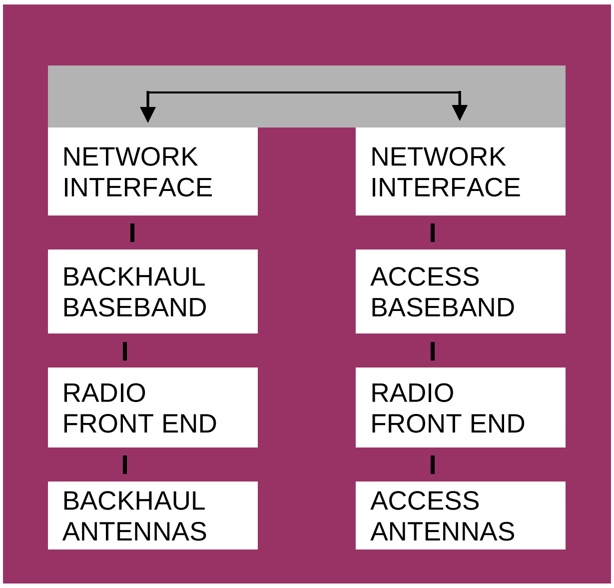
b) Dual Unit Relay Station (DURS) . This model is composed in two units: outdoor bauckhaul an indoor base station / access unit.

The above two models are showed below.

SURS



DURS



Baseband Sub systems

It is based on open SoC (System on Chip) platform for WiMAX which has high-capacity in band wireless backhaul capability. The above technique has been implied on two identical HW platforms and each of them based on single chip.

Baseband subsystem implements PHY and MAC functionality. PHY sub system integrates with MIMO (Multiple input multiple output) – OFDMA modulation. Its core named DSP and the next significant component is network processor which is comprised of 4 RISC (from Tensilica) high speed processors. It also includes 3 ARM control CPUs running the MAC control plane, networking and management software.

Radio Front End Sub system

This sub system performs processing and conversion of transmitted and received MIMO backhaul and access signals. It is located between Baseband and Relay Antennas. It gives additional tailoring and specific operations following two dimensions : a) the frequency band: currently there are 4 frequencies used within the WiMAX space (2.3 GHz, 2,5 GHz, 3,5 GHz and 5 GHz), and b)the output power: the total output power has strong implications on the area covered like its power dissipation, cell size and cost.

The output power of our prototype Relay Station is 27 – 30 dBm (0.5-1W). This level of power depends on system size, cost and in high capacity dense urban cases.

Network Interface Sub system

This sub system plays coordinator role between upper layer data and management network entities. Its main operations are the following:

It configures and synchronizes overall system of baseband and RF modules.

It acts like interface to Element Management and Network Management Systems.

It shares synchronization information between External and Internal Units (in DURS Mode).

It implies tunnelling and Quality of Service mechanisms for Network Base Relay.

Antennas Sub system

It support MIMO access and backhaul operation. Different antennas can be attached to Relay unit depending on specific coverage requirements. Backhaul antennas is required to has high directionality LoS (Line of Sight) MIMO path while Access Antennas can be omni-directional (it radiates power uniformly in one plane, with radiated power decreasing with elevation angle above and below plane, dropping to zero on the antenna's axis) or sectorial (each antenna covers a sector of plane in angle of 360°).

Prototype Relay Station dimensions

Size : 20 cm X 25 cm X 35 cm

Weight: < 14kgr.

It needs 90-240 VAC, and its power consumption is < 100W.

Ethernet features:

Electrical interface: 10 / 100Base T

Outdoor connector IP6 weatherproof RJ-45,

Indoor connector: RJ-45,

MAC - IPv4 over 802.3/Ethernet,

MAC - 802.3Q/VLAN.

Environmental Specifications

Operating Temperature: - 40° to 55° C -40° to 131° F

Operating relative humidity (non-condensing): 15% to 100 %.

Wind survivability > 165mph.

RS Frame Structure

Our model the frame is partitioned into 4 segments:

RS transmits to MS (Access Download)

RS receives from MRBS (Backhaul download)

RS receives from MS (Access Uplink)

RS transmits to MRBS (Backhaul Uplink).

DL ACCESS	DL BACKHAUL	UL ACCESS	UL BACKHAUL

--- Frame / 5 msec --

Relay Station access link based on IEEE 802.16e according to the following functions: Contention-based initial ranging, Periodic ranging and Bandwidth requests.

The link between Relay Station and MS /SS (Access link) supports intelligent HARQ (Hybrid Automatic Repeater Request) type of channel. HARQ has buffering capability which indicated by two parameters:

a) Number of bits per channel – Relay Station can buffer 16.384 soft-bits for both Uplink and Downlink.

b) Aggregation flag- when this flag is clear, the number of bits is counted separately for each channel, otherwise when the flag is set buffering capability may be shared between channels.

MAC specification

MAC specifications are based on 802.16e standards of IEEE. This prototype implements a fixed and non transparent Relay Station with distributed scheduling. RS supports mobility like location based services and scanning and association, Multicast feature, Handover like Sleep and Idle Mode, Neighbour Advertisement, CID (Connection Identifier based in forwarding type) and centralized scheduling including MAP distribution (The RS builds its own maps independency of the MRBS, using CID).

MAC supports also, Quality of Service transparency while moving from base station portion to the backhaul portion of the relay connection. BS can initiate Dynamic Service Flow according the following mode: creation / Change / Deletion in Relay Station.

RS supports security mode performing MS Authentication procedure during network entry. User data encryption /decryption is performed at the RS.

MIMO antenna

The introduction of multiple antenna (MIMO- Multiple Input Multiple Output) at the Relay Station, the spectral efficiency is improved because it exploits spatial multiplexing, diversity and interference mitigation gains. The concept is to split the main data stream into multiple independent spatial sub streams and send it to number of Relays. So the close loop MIMO applied between MRBS and RS and the goals are to maximize backhaul and coverage efficiency in the fields. MIMO transmits over the link with two orthogonal polarizations.

7. Chapter IV - Discussion of Results & Analyses

Research gaps

Why we have chosen this architectural solution? Why we have leaded to imply new Relay Stations? This Project scrutinizes advantages of new Relay Station compatible with WiMAX contrast with lack of Relay Station of new wireless technology and Ethernet Network. The aim is to cover the weakness of existing WiMAX applications in the field.

1. Limited bandwidth and/or insufficient wire-line capacity

Each Operator buys a licence to use a specific bandwidth of ITU and Specific bandwidth has been given for specific application. Consequently, the bandwidth should be used with wise manner. For example the internet through put could require 1 or 2 or more Mbps and for VoIP 100kbps is enough. The project uses such technologies in RS that can reuse and use the bandwidth with wise way exploit specific algorithms. In addition there are places which wire line does not exist due to impervious ground.

2. Low SNR (Signal to Noise Rate) at cell edge.

SNR measures how much a signal has been corrupted by noise. It is defined as the ratio of signal power to the noise power corrupting the signal. When the ratio is higher than 1:1 indicates more signal than noise. Some times it refers to the ratio of useful information to false or irrelevant data in a conversation or exchange. Low SNR means low power of signal due to long distance or not good coverage or lot of noise which can be random depends on environment changes and antennas situation or white noise introduced by devices.

3. Coverage holes due to shadowing and obstacles and Out-of-range clusters of users.

There are coverage problems in cells mainly in urban areas so there are spaces which there are no any signal. The first technology of WiMAX solves partially this problem changing the modulation but it reduces the speed. This project brings new antenna technology: Adaptive Antenna System (AAS) which used by the relay will cover the area required, without significant interference to nearby cells, increasing the efficiency of the system in terms of frequency reuse. It could be widely applied in urban areas where coverage is obstructed by buildings around the subscriber station.

4. Non-uniformly distributed traffic load (e.g. hot spots)

Another problem is low level of bit rate on the data transmitted to the subscribers. The distance between the base station and the subscriber is long or the environment introduces a lot of interference reducing the available data rate of the user. The use of a relay station will improve the provided service to the end-user.

5. The problem of existing wireless cells is that they use big antennas which consequently bring panic that has hampered significantly the deployment of cells in urban areas with visible antenna infrastructure, a fact that has great impact on the OPEX of the network due to the growth of roof right cost.

6. Many technologies. In today's globalization economy users expect ubiquitous connectivity to networked resources. This increased demand for connectivity and access to information sources and network services has led the way towards the massive development of vast variety of advanced mobile services. So today, there are many telecom technologies offer separated services. Instant messaging systems, location based services, mobile internet are only some of the most indicative and most fundamental mobile applications that have extended the service horizon of the mobile users. In this point a term "convergence" is coming to add. Convergence and integration between voice and data, fixed and mobile is going to happened through Next Generation Network and IP Multimedia Sub-system. This project comes to offer high mobility access using MMR (Mobile Multi hop Relay) stations, making easy the way of convergence and integration of Telecom technologies.

7. Prohibitive installation and operating costs (backhaul is large fraction).

While Compress technologies (BTS) of wireless access drives compact modules with more intelligence/processing it also reduces the cost of base-station equipment, they still rely on a dedicated backhaul which results in significant CAPEX and OPEX to the network operator. On one hand it should be small, cost effective and easy to install to enable mass deployment in indoor and outdoor environments to create relatively small areas with excellent coverage and high capacity availability. On the other hand it does not require any dedicated backhaul equipment as it receives its capacity from centralized base-stations via the same resources used for the access service.

Laboratory tests

Lab tests have been held in OTE premises (laboratory conditions) by scientific team.

Iperf and Spirent are the main equipments which have been used for throughput measurement and QoS types. It has been checked in Real Time services (RT) like video and non-RT like data.

The quality of provided services within accepted levels have been verified. In order to achieve this the following equipments have been used: PESQ - which voice quality has been measured, PEVQ which checks video quality and MOS which checks quality after compression.

Latency

MRBS has less than 100ms latency for roundtrip ping. It is a maximum permitted level for Best Effort type of QoS. Round trip time depends on both terminations BS and CPE and on the middle RS.

Throughput

Total throughput from MRBS to RS to MS/SS is greater than 7 Mbps and 20K 64-byte packets per second, in a 10 MHz channel.

The following table shows the Antenna receiver sensitivity:

Table 8 – Antenna receiver sensitivity

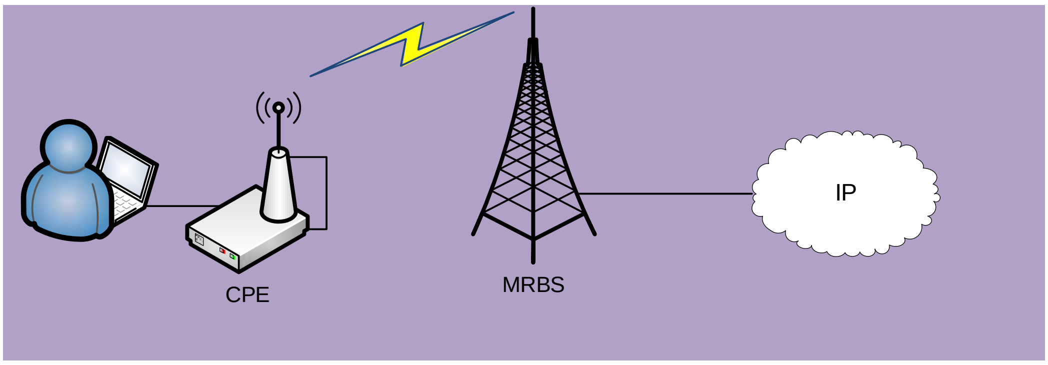
MCS	Min Required SNR	PDU Size (bytes) [dB]	Slots Per PDU	PER (BER=1e-6)	Sensitivity (dBm)
QPSK 1/2	2.9	60	10	0.048%	-100.1
QPSK 3/4	6.3	54	6	0.0432%	-98.9
16QAM 1/2	8.6	60	5	0.048%	-97.4
16QAM 3/4	12.7	54	3	0.0432%	-95.5

Field tests

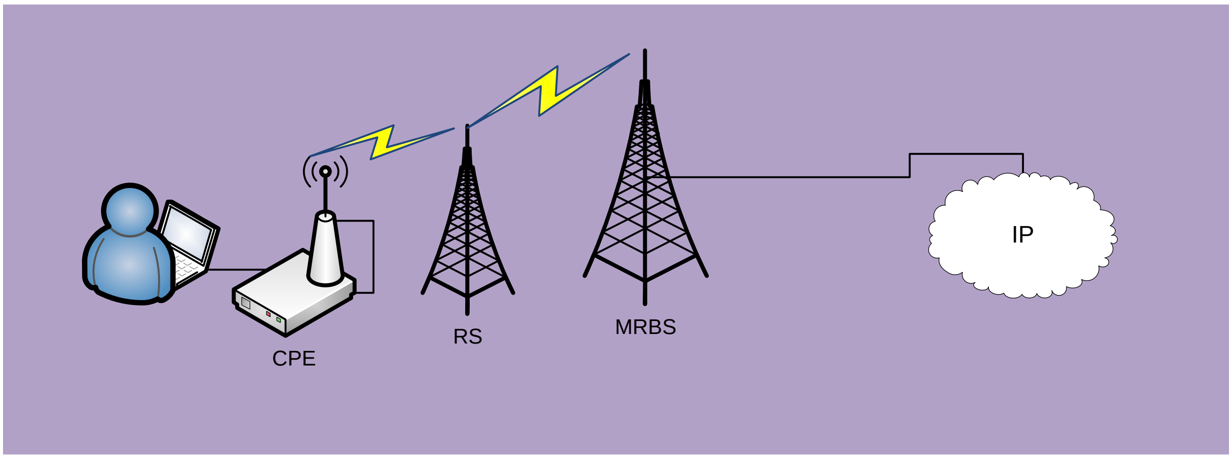
Measurement Conditions

There are 2 topologies :

1. There is a MRBS which is connected directly with CPE (customer private equipment),



2. There are a MRBS and a Relay Station which supply CPE.



Basic physical connectivity test

Using Figure 1 topology, all possible CPEs (USB cards, PCMCIA, indoor and outdoor standalone CPEs) have been verified that they can successfully register to the MRBS as well as to RS. In each case, CPEs were remained connected in MRBS for at least 10 minutes without any problem.

Table 9 – Result of physical connectivity test

Test	Result	Comments
Physical Connection with MRBS (USB, PCMCIA, indoor and outdoor units)	OK	No Comments Field test
Physical Connection with RS (USB, PCMCIA, indoor and outdoor units)	OK	No Comments Field test

Layer-3 (IP) connectivity test

A PC has been connected to the backbone of the MRBS and checked that either got an IP from a DHCP server or it had a static IP address. A CPE was connected with MRBS and after ensuring that it had obtained an IP address in the same subnet (VLAN) as the backbone-PC mentioned before verify layer 3 connectivity using 'ping' command for two minutes. Specifically type ping x.x.x.x –t 120 (where x.x.x.x is the IP address of the destination) and any lost packet has been checked as well as the network delay and the results depicts in the following table. Repeat this procedure for both uplink and downlink.

Table 10 – Layer -3 test

Test	Result	Lost packets (%)	Average delay (ms)
Layer-3 connectivity test in uplink	OK	0	59ms
Layer-3 connectivity test in downlink	OK	0	50ms

Test	Result	Comments
Adaptive Coding and Modulation test	OK	NO Comments

Adaptive Coding and Modulation test

Place a CPE in a relay station's coverage area and record the modulation and coding scheme achieved. Start walking towards the RS and check if adaptive modulation and coding functionality works as expected (see that as SNR is getting higher, CPE moves to more efficient AMC schemes).

MRBS performance test (without MIMO)

One MRBS is activated and connectivity and performance at different locations and link conditions were being checked. Specifically, a vehicle is used with a CPE and connected to the MRBS and it was being driven along a pre-determined path toward the cell boundary keeping the connection between CPE and MRBS. Receive Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR) has been recorded as well as the modulation and coding scheme achieved at different distances from the MRBS and in different environments (LOS, nLOS, NLOS). The measurements has been repeated for both uplink and downlink

Distance	Condition	RSSI		SNR		Modulation and coding		Performance (Mbps)	
		Uplink	Downlink	Uplink	Uplink	Uplink	Downlink	Uplink	Downlink
latit:38 2.944 longitude: 23 47.230	NLOS	-76	-84	22	17.9	QAM 64 1/2	QAM 16 1/2	UDP:2.5 TCP:2.51	UDP:2.4 TCP:2.5
latit :38 2.903 longitude 23 47.330	NLOS	-70.5	-82	25	17.1	QAM 64 1/2	QAM 16 ½	UDP:2.45 TCP:2.82	UDP:3.2 TCP:3.3
latit :38 2.962 longitude 23 47.361	nLOS	-73	-59	26	31.2	QAM 64 1/2	QAM 64 3/4	UDP:2.7 TCP:2.85	UDP:7.11 TCP:7.14
latit :38 3.148 longitude 23 47.380	NLOS	-80	-92.5	21.5	7.3	QAM 64 ½	QPSK 1/2	UDP: 0.95 TCP:0.86	UDP:1.67 TCP:1.64
latit :38 2.956 longitude 23 47.412	NLOS/nLOS	-74	-77	24.2	20	QAM 64 ½	QAM 16 3/4	UDP:1.95 TCP:2.3	UDP:4.75 TCP:4.9
latit :38 2.958 longitude 23 47.336	LOS	-71	-63.5	27	30.8	QAM 64 1/2	QAM 64 3/4	UDP:2.83 TCP:2.84	UDP:7.1 TCP:7.35

RS coverage improvement and performance test (without MIMO)

A Relay Station was power up and connected with the MRBS. At first, the CPE was near with location of Relay Station where the signal was 0 (marginal) and it was moved in order to improve the coverage.

Table 11 - SNR

Test	Position	Comments (SNR, RSSI improvement %)
RS coverage improvement test (MIMO disabled)	Latitude: 38.05010 Longitude: 23.79068	UDP DL: 3.3 (1.65) UDP UL: 2 (0.61) RSSI: -79 (-92) SNR: 18 (7.7)

In addition, a vehicle is used with a CPE and connected to RS, it was driven along a pre-determined path toward the cell boundary and keeping the connection between CPE and RS. Receive Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR) have been recorded as well as the modulation and coding scheme achieved at different distances from the MRBS and in different environments (LOS, nLOS, NLOS). The measurements have been repeated for both uplink and downlink.

Long Duration Throughput test

With one hop topology, a CPE was located inside the Relay cell and a throughput test with the other peer connected behind the MRBS has been performed. A continuous data transfer has been kept for an hour so as to verify that the performance of the link was constant. CPE service flow was unlimited using best effort (BE) service class.

Table 12 – Throughput test

Distance	Condition	RSSI		SNR		Modulation and coding		Performance (Mbps)	
		Uplink	Downlink	Uplink	Uplink	Uplink	Downlink	Uplink	Downlink
latit :38 .04697 longitude 23.78491	NLOS	-71	-82	24	16	QAM 64 1/2	QPSK 3/4	UDP:1.9 TCP:1.7	UDP:2.4 TCP:2.5
latit 38.04732 longitude 23.78657	NLOS	-69	-76	25	23	QAM 64 1/2	QAM 16 ½	UDP:2.2 TCP:2.3	UDP:3.5 TCP:3.8
latit :38.04529 longitude 23.79099	NLOS	-79	-93	17	7	QAM 64 3/4	QPSK 1/2	UDP:0.45 TCP:0.3	UDP:1.03 TCP:1.28
latit 38.04713 longitude 23.78740	LOS	-70.5	-59	28	31.7	QAM 64 ½	QAM 64 3/4	UDP: 2.2 TCP:2.2	UDP:6.7 TCP:2.5
πλ:38.04978 longitude 23.78617	NLOS	-69	-85.6	27.5	12.2	QAM 64 ½	QPSK 3/4	UDP:2.1 TCP:2.2	UDP:2.4 TCP:2.3
latit :38.05078 longitude 23.78847	LOS	-69.5	-58	27	32	QAM 64 1/2	QAM 64 3/4	UDP:2.25 TCP:2.25	UDP:7 TCP:4.4

Test Description	Result	Comments
Long Duration Throughput Test	TCP Down: 7.42Mbps	Stable

Measurements

Throughput Measurements

Below measurements have been taken by iperf and IXChariot.

Spots: MRBS in OTE Academy – Amarousion

RS in Ag Konstantinou – Amarouyosion

Distance between MRBS and RS is approximately 100 m.

Each channel size: 10 MHz

Frequency: MRBS = 3,491,500 Hz and RS = 3,521,500 Hz.

MRBS

1. UDP Layer

Downlink = 7.1 Mbps

Uplink = 2.4 Mbps

2. TCP Layer

Downlink = 7.3 Mbps

Uplink = 2.8 Mbps

Relay Station

1. UDP Layer

Downlink = 7.12 Mbps

Uplink = 2.00 Mbps

2. TCP Layer

Downlink = 7.40 Mbps

Uplink = 1.8 Mbps

8. Chapter V Impact, Recommendations & Future Work

Impact

For WiMAX networks, the IEEE has started in 2006 to work on 802.16j "Mobile Multihop Relay" (MMR). The basic idea behind MMR is to allow WiMAX base stations which do not have a backhaul connection to communicate with base stations that do. On the one hand this will of course reduce the bandwidth available to users in the cells involved in relaying packets. On the other hand it's an elegant way to save costs and extend network coverage into areas where connecting a base station directly to the network via a fixed line connection is economically or technically not feasible.

WiMAX combining with RS gives a promised available IP in the future. It will have a great successful in commercial market.

Institutions and bigger organizations like Hotels, colleges, airports offer hot-spots that allow free use from any point. Routers are set up with-in the premises to enable WiMAX technology internet access to connect to devices. There are a lot of university campuses that have wireless internet network provided within. Thus student can have source o information from anywhere, send across documents and work with no restriction. These hot spots have limited coverage consequently the number of antennas has been increased in order to cover non sight areas and there is limited in throughput rate (using Wi Fi). Using Relay Station promises a wide broad band services in the areas where coverage are limited and the area when you move out of the coverage area, you loose internet access and connectivity.

Today, WiMAX is the latest technology offering. WiMAX stands for Worldwide Interoperability for Microwave Access. WiMAX is also known widely as 4G WiMAX since it is the 4th generation improvisation in communication technology. The 4G WiMAX service supports a download speed between 3Mbps to as much as 10Mbps and an upload speed of maximum 1MB per second. WiMAX is an excellent solution in distant and remote places where high speed internet access via DSL and Cable network is not possible. Thus even if you are away from the city premises you can still access high speed internet via WiMAX broadband service.

Recommendations

Standard 802.16 is being enhanced like 802.16m and WiMAX Forum working groups working on it taking account all regarding recommendations.

Recommendations can be extended in security field, maybe, for specific applications.

Radiation

Another recommendation could be the effectiveness of radiation. It is commit with license of frequency. Nevertheless the radiation of Relay Station and WiMAX (density of power) are under correspondent level which European Community has laid into force as recommendation: L 199 (1999/519/EC), 30-7-1999, regarding "the limits of exposure on human due to electromagnetic fields in frequency between 0 Hz - 300 GHz " . In Greece there are articles of law 3431, 2 up to 4 of 53571/3839 (1105/B/6-9-2000). The limits of radiation are reduced in cases of where there are hospitals, schools, kinder gardens, nursing homes and other sensitive cases.

Future work

Relay Station into a network was not pre-designed or standardized to support relays. For instance using this architecture a network with 802.16e base-stations or even a fixed WiMAX 802.16d network could support relay deployment without a need to upgrade the already deployed base-stations HW or SW.

Study how to improve the delay and latency during handover and the impact of Relay Station in WiMAX.

Study the impact of more than two hops using Relay Station in WIMAX communication and how to improve its possibly problems.

Study how to enhance the features of Relay Station using the edge of technology.

Study the impact of new antenna using also new technology.

9. Chapter VI   Project Review

The new standard 802.16j relay network architecture defines all these functions associated with the addition of relay (RS) into the network at the MAC layer 2 within the relay supporting base-station (MRBS). Prototype of relay Station or MRBS upgrades the infrastructure of WiMAX with low OPEX and CAPEX because it uses the existing system.

Measurements were very interesting to depict how from theory comes to real world and to find out if there were problems in transmission, coverage or in rates of speeds (upload / download).

Project does not roll out according to the initial schedule. It shifted due to delay in Prototype Relay Station construction.

Objectives have been done and approved.

- A new architecture has been implied in based network improving features with new elements : Base Station (MRBS), Relay Station (RS) and Subscriber Station (SS).
- Interoperability between base station – relay station – mobile station was successful.
- Lab Architecture Set up has been achieved.
- Lab Test using appropriate measurement equipment has brought very good results.

After that set up of System in Field done without any significant problem in installation of equipment and test procedure was started.

- Field Test Procedure has been started with difficulty up to calibrate and configured the test equipments. After that no significant problem has been faced.

WiMAX Relay system gave us a special satisfaction for this project.

Risk was one of primary components so it has been controlled and mitigated. The first target of this project is to have the required quality of elements. So it needs more than expected time to construct the prototype Relay Station and Main Relay Base Station. This work package belongs to the previous team which participates in project like any innovative program which involve in new technologies. Finally, they did at the best in order to produce a quality product in the sorter time.

Lab and field test procedure carried out without delay but it was not possible to use more than one relay Station and measure the network with two hops. However this case is avoided. Less scenarios were used and the whole project managed well.

The Budget has allocated from European Community and was sufficient up to now for this project.

10. Chapter VII References

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